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ON A CASE OF THE RAPID EXTERIOR CORROSION OF AN IRON WATER-MAIN.

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I. STATEMENT OF THE CASE, BY MR. BORDEN.

DURING the summer of 1884, unmistakable signs of a leak presented themselves on the line of a six-inch main on the premises of the Fall River Iron Works, situated upon the shore of Mount Hope Bay, where the pressure upon the main was one hundred and twenty pounds per square inch.

On uncovering the pipe it was found that a change had taken place in the material of which it had been composed. The pipe was soft, being easily cut with a knife; was smooth and greasy, having the appearance of plumbago. Investigation proved that six pipes, or seventy-two feet, had been more or less affected. In some places the change extended nearly through the pipe, while at others, but a short distance from the first, the change was much less marked. The inner side of the pipe was perfect as when laid, the coating of "coal-tar varnish" remaining intact. The pipe had been in the ground about nine years.

Following is a section of the specifications relating to the quality of material of which the pipe should be composed, and there has never been any reason to suppose the pipe was not up to the standard as called for.

"*Quality of Metal.*—The metal shall be strong, tough and coarse-grained, with the carbon combined and not in the form of graphite, and as hard as the case will admit, but not too hard to be readily cut and drilled, and shall be re-melted from pigs of gray iron in a cupola or air-furnace, without any admixture of cinder iron or other inferior metal, and shall have a tensile strength of at least 16,000 pounds per square inch."

The corrosion has not been the same on all sides of the pipe, nor has the change followed any rule as to position. In some places it was most on the top of the pipe, as it lay in the ground, in others on one side, again on the other side, and in other places on the bottom.

Although the outside of the pipe was soft when taken out of the ground it has since become quite hard. On the premises of the iron works there are about 800 feet of pipe made and laid apparently under the same circumstances and subject to the same conditions, yet only this piece has undergone the change.

A sluice-way forming an outlet from Crab Pond to Mount Hope Bay, and one from works of the American Printing Company, through which are discharged the spent liquors from that establishment might appear to afford an explanation of the whole matter, but on noting that the pipe was taken from points not within one hundred feet of the sluice-way, while the pipe over the sluice-way is intact, it

seems as if some other cause would have to be found.

At the northwesterly corner of the nail mill is a point used for at least twenty-five years by a large number of men as a urinal. At first it seemed probable that this might have had some effect upon the pipe, but it is found that a hydrant within five feet of the said corner was not affected. This leads us to suspect this is not the cause sought for.

When the wharf was built the wall was laid up and a portion back of it (shown by dotted lines on the plan (was not filled for several years. Into this pond hole the drip from the rolls of the iron works, and the drainage from the wheel pit of the engine was discharged until the hole was filled up, and it is even a question if it is not now allowed to discharge there, and find its way to the Bay through the filling, which it could readily do. The fact that this is where the pipe had undergone the greatest change leads us to look at this with some suspicion. The drip from the rolls would, of course, be warm. The main here is a "dead end," intended simply for fire-protection, consequently the water might remain therein some time without being renewed, and become quite warm, keeping the pipe in the best condition to be acted upon by salt water. It is conceded hereabout that warm salt water is damaging to cast iron, more especially if oil or other grease is present.

Some years since the condenser of an engine, so located that the tide reached it, was affected the same way, and it was then thought to have been caused by the combined action of heat and salt water. At that time it was stated that the wrought iron, though subjected to the same influences, was not affected.

The whole of this pipe is laid on made land, most of the filling being cinders, iron slag from puddling furnaces, and such other refuse as is usually found about an "iron works." The soil is of such a nature that the water from the bay would readily find its way to, and even beyond the pipe, covering it with salt water twice in twenty-four hours, leaving it more or less immersed from six to eight hours out of the twenty-four. One would hardly suppose that, with a thickness of but one-eighth of an inch, the pipe would stand the pressure of one hundred and twenty pounds per square inch, but such was the case.

An attempt has been made to charge the change to poor material, but of the 56.6 miles of pipe in the city, this is the first and only thing of the kind found. Again, the pipes taken out were not all of one lot. Of the six, one was made by R. D. Wood & Co., three by the Gloucester Iron Works, and one by the Warren Foundry and Machine Company. The remaining pipe was so badly broken in taking out that it was not identified.

II. Chemical Study of the Corrosion, By Professor Nichols.

Some time ago, I received from my colleague, the President of this Society, a specimen of the corroded pipe referred to by Mr. Borden in the earlier part of this paper. Since then I have received other specimens from Mr. Borden, together with samples of the material in which the pipe lay, and other objects which, it was thought, might throw light upon the cause of the corrosion.

The specimen first received by me was a ring cut from a pipe on which the corrosion was very marked. An inspection of the cut surface showed three tolerably well defined layers: within, a ring of apparently unaltered iron; without, a ring of a brown substance bearing no resemblance to the original iron, being easily cut with a knife and having a greasy feel; between the two, a layer full of black, metallic-looking particles, and easily reduced to a brown powder. I speak of these layers as *tolerably* well defined, because, while they appeared distinct on casual observation, closer inspection showed that they ran into each other and could not be separated, one from the next overlying or underlying layer. In other specimens of the pipe only two layers could be made out, the inner apparently unaltered iron, the outer corresponding in character to the middle layer of the specimen first received. The corrosion had not taken place uniformly, so that the bounding surfaces of the layers were not concentric, but a section through the pipe had the appearance indicated in the figure given by Mr. Borden. In some cases, owing to lack of homogeneousness in the pipe, the corrosion assumed the form of pitting, the pits being filled with a mate-

rial corresponding to the outer layer of the first specimen described. This outer layer, where the corrosion was complete and where no iron remained in the metallic condition, is perhaps the most interesting. It is light brown, almost yellowish in color, but is full of shining black particles. When heated, it gives off some white fumes and the odor of acrolein, glows, and what remains is of a darker color, almost black. The black particles scattered through the mass are somewhat magnetic before and after heating. When the substance is treated with hydrochloric acid it gives off sulphuretted hydrogen gas; the residue is black, but becomes white on ignition. The results of the analytical determinations are as follows, the second column merely presenting the statement in slightly different form, calculated from the same data:

	Per cent.	
Moisture	6.62	6.62
Oil, etc., before hydrochloric acid	0.96	0.96
Oil, etc., after hydrochloric acid	0.61	0.61
Sulphur	0.41	.....
Sulphur calculated as sulphide of iron	.....	1.12
Phosphorus	2.20	.....
Phosphorus calculated as phosphoric acid (P_2O_5)	.....	5.04
Graphite	14.75	14.75
Non-graphitic carbon	undet.	undet.
Silicon	9.94	.....
Silicon calculated as silica (SiO_2)	.....	21.30
Iron	32.73	.....
Iron calculated as oxide of iron (Fe_2O_3)*	.....	45.75
Copper	0.22	0.22
Manganese	0.53	.....
Manganese calculated as oxide (Mn_3O_4)	.....	0.74
Alumina, chromium, lime, magnesia, chlorine, sulphates	traces.	.....
		97.10

* After deducting the amount contained in the sulphide of iron. Calculated as the oxide Fe_3O_4 the amount would be 44.22 per cent.

As these figures may meet the eyes of chemists, it is necessary to make a few remarks which will be of more interest to them than to civil engineers. In the first place, no two samples precisely alike could be taken from such a mass, and the results of examinations made by different persons would, no doubt, vary on this account. The moisture was determined by drying the substance at 110° C., until a practically constant weight was obtained. The "oil, etc., before hydrochloric acid" represents what was extracted by ether from the dried substance. This was dried at 100° C., but a perfectly constant weight could not be obtained. When heated, it partly volatilized and partly burned with an odor of acrolein, and left no mineral residue. This oil or grease is partly due to the remains of the coating (coal-tar and linseed oil) with which the pipes were originally covered, and partly, probably, to hydrocarbons in the iron or formed during the corrosion; partly also, in all probability, to oil from the tool used to cut the pipe; but I believe that this is not all. In fact, I found that ether would extract similar oil or grease from the different samples which I had of the slag, or cinder, in which the pipe was bedded, and no doubt this comes from the greasy waste water from the rolling-mill, which, as Mr. Borden says, used to drain into this locality. After treatment with hydrochloric acid, the residue yielded an additional quantity of oil when extracted with ether. This may be due to the presence of an oleate or other fatty salt in the mixture; but oleate of copper or iron were not identified. I propose to study this matter further with another sample, which has not been touched with a tool, and which cannot, therefore, have any oil from this source.

The sulphur is present as sulphide of iron, without much doubt. The phosphorus appears to exist to a slight extent, even in the outside layer, as phosphide of iron—mainly, however, as a (basic) phosphate of iron; and I am inclined to think that this compound, which is readily dissolved out by dilute hydrochloric acid, is what gives the brown color to the mass. The carbon is probably there partly as graphite, and partly in the form of carbide of iron, which is formed when gray cast iron is corroded or dissolved slowly in dilute acids, and to which the formula of Fe_3C has been assigned by Karsten. This would count as graphitic carbon in the analysis. The non-graphitic carbon was not determined, as it would have been impossible to distinguish between that left from the original iron and that due to the protective coating, which is not simply a coating, but is absorbed by the iron.

The silicon is mainly, if not wholly, present in the form of the oxide, silica, but whether it is combined with the oxide of iron forming silicate of iron, or whether the oxide of iron and the silica are simply mixed together mechanically, is a problem which it would be difficult, if not impossible, to solve. The material does not gelatinize with hydrochloric acid, and caustic potash dissolves some of the silica (perhaps about one-half).

The condition in which the iron exists is an unsolved, if not insoluble, problem. Some is there, no doubt, as sulphide, some as phosphide, some as silicide, some as phosphate, perhaps some as silicate. As the material does not precipitate copper from a solution of the sulphate, I do not think there is any metallic iron; as the carbide of iron is magnetic, I do not feel sure of the presence of magnetic oxide, although it is probably there. It was impossible to determine how much iron was in the ferrous condition, on account of the presence of sulphide of iron and of organic reducing substances. Some of the iron may be in the form of a hydroxide like limonite, and the brown color of the mass may be due to this, rather than to a basic phosphate. These conjectures may be taken for what they are worth. If asked to state intelligibly to one not much versed in chemistry, what the corroded material was, I should say that it is mainly oxide of iron and silica, possibly in combination as silicate of iron, together with some 15 per cent. of graphite or plumbago, some 6½ per cent. of moisture, and some 2 per cent. of phosphorus, which is probably there as phosphate of iron, and which corresponds to about 15 per cent. of the phosphate. It having been stated elsewhere that a considerable percentage of alumina exists in the corroded material, I will say that I have been unable to discover more than mere traces.

As to the cause of the very rapid corrosion, various theories have been proposed or have suggested themselves. With reference to the general matter of the corrosion of cast (and wrought) iron in salt (and fresh) water, the classic experiments are those of Mallet, recorded in the British Association Reports for 1838, 1840, and 1843. From his experiments, extending over a period of 387 days, Mallet calculated the amount of corrosion which would take place at the same rate in a century,* and found that, with different varieties of cast iron, the average loss of weight per superficial foot in a century would vary from 11.58 pounds to 16.34 pounds, and the average depth of corrosion from 0.306 inch to 0.431 inch in the same time. This calculation of from three to four-tenths of an inch in a century as the depth of corrosion in cast iron, was found to be somewhat low by the examination of guns taken from the wreck of the *Edgar*, which had been upward of 129 years under water. Here the corrosion was found to be about seven-eighths of an inch on the average. Iron from the Royal George was found, after an immersion of 59 years, to be corroded from one-half to three-fourths of an inch in depth.

Mallet found that in foul sea-water the corrosion took place more rapidly than in clean sea-water, but with nothing like the rapidity of the case before us. His experiments were on specimens of iron wholly and continuously submerged; the alternate exposure to air and sea-water, or to water as salt as that at Fall River,† we should expect to cause an increased corrosion, but this certainly cannot be the sole cause here, because beyond the por-

* Report of the British Association for the Advancement of Science, x. (1840), p. 299.

† See further on, next page.

tion of pipe affected, there is other pipe which has been likewise alternately exposed and submerged without being corroded. It has been thought that the corrosion has been caused by the material in which the pipe was bedded; that some acid or corrosive substance was developed by the decomposition of the slag, or cinder. Some probability attaches to this view, because cases have been known where steam-pipes have been corroded by the escape of steam in the slag-wool in which they were packed. This Prof. Egleston* ascribes to the formation of sulphuric acid from the sulphur in the slag-wool. I must confess that I cannot quite see how an acid should be developed under the existing conditions, and I kept for a long time some of the finely-powdered cinder in contact with water taken from the spot, without being able to discover the development of any acid. I have an experiment in progress which may throw some light upon the matter. In two glass jars I buried small weighed bars of cast iron (portions of the same casting) in powdered cinder (two different samples), and in another jar buried a piece of the same iron in clean sand. These jars were filled with water from Fall River; every morning the water is drawn off and every evening replaced, so that the iron is alternately covered with water and exposed wet to the action of air. After the experiment had gone on for about four weeks, the pieces of iron were removed, cleaned, and weighed. It was found that the iron buried in clean Berkshire sand, and which originally weighed 87.49 grams, had lost 0.15 gram in weight. The pieces buried in the slag weighed the same as at first. I feared the slag might have been too finely powdered, so that the water did not drain away thoroughly, and the experiment is now going on with more coarsely powdered slag. Meanwhile the water has developed no acid reaction.

Another difficulty in the way of considering the slag as the cause of the trouble is that some of the uncorroded pipe lies in similar material. Mr. Borden sent me three samples of filling from the pipe trench: No. 1, from the west end of the decayed pipe, where the pipe was good; No. 2, from the middle ground, where the pipe was bad; No. 3, from the east end, where the pipe was good. The sample No. 1 was a clayey gravel, but Nos. 2 and 3 were essentially the same slag, and there seemed no reason why, if No. 2 was corrosive, No. 3 should not be so likewise. Samples of water were also sent at the same time from the three localities. They proved to be alike in their salinity, as appears from the following statement:

	Percentage of— Combined chlorine.	Total solids.
No. 1	1.43	2.86
2	1.48	2.86
3	1.49	2.82

Samples of the three materials in which the pipe was bedded at these different points were then taken and placed in separate beakers, and each covered with water from its own locality. The water was poured off every evening and poured on again every morning, for about a fortnight. The total solid material contained in the water after this treatment was then determined:

	Percentage of total solids. Originally.	After treatment.
No. 1	2.86	2.96
2	2.86	3.74
3	2.83	3.24

This would also indicate the similarity of the two samples, Nos. 2 and 3.

The cinder in which the pipes are bedded contains a small amount of copper, which might be looked upon as an agent of corrosion. Undoubtedly, if the copper was dissolved out from the slag by the salt water, the iron would be corroded by the solution, and copper would be left on the iron. The amount, however, even in the outside layer, is so trifling that it does not seem as if this could be concerned in the action, and copper occurs in the slag in which the non-corroded pipe lay as well as in that around the corroded pipe.

It is known* that iron structures immersed partly in salt and partly in fresh, or brackish, water are corroded somewhat rapidly, on account of galvanic action between the portions of iron immersed in the liquids of different densities. It suggested itself that the fresher water draining from the rolling mill

* Trans. Am. Soc. Civ. Engr's. XII. (1883), p. 253-261.

* Mallet, Br. Assoc. Rep., X. (1840), p. 227.

might overlie the salter water below and bring about this condition, but samples of water which were taken for me by Mr. Borden at different stages of the tide, proved to be of essentially the same salinity;

	Total solid matter. Per cent.
No. I. Full tide.....	2.59
No. II. Tide falling when at top of pipe.....	2.64
No. III. Tide rising.....	2.61

It has been further suggested that the fault was in the original iron; but, as Mr. Borden remarks, this can hardly be the case, as pipes furnished by three different makers were corroded. I procured a piece of the spigot end of one of the pipes, this end being naturally protected from corrosion, and made a partial analysis, which appears in the table below. I have had no experience with the iron generally used for such water mains, but see no reason to suppose the iron at fault.

The most serious part of the problem before us is not to determine why the pipe has corroded, but why it has corroded here so much more rapidly than on either side of the 72 feet length, most of the conditions seeming to be the same. I may say that I have been unable to visit the locality, and it is within the bounds of possibility, although not very likely, that a personal visit might suggest some things which I have not considered. It is also possible that the cause of the corrosion is one that has acted in the past, but is not acting at present. This we cannot know until the new pipe has been longer in position. With what light I have at present, it seems to me most likely that the corrosion is due, not to any one single cause, but rather to a combination of circumstances which happened to work together to produce the observed result. The pipe is bedded in a very porous material, in which, as the water recedes, the air must circulate freely, but which probably retains enough moisture to keep the pipe wet nearly all the time, even when not actually covered by water. Now, as Mallet states,* "the conditions the most favorable possible for rapid oxydation of iron consist in its exposure to 'wet and dry,' or to air, covered with a film of water constantly renewed."

Moreover, from Mr. Borden's statement, it appears that the temperature is such as to favor chemical action. Mallet found that sea-water, at a temperature of 115° Fahr., corroded iron rapidly. It is not likely that the Fall River brackish water reaches that temperature, but still the temperature is probably a factor in the matter. When the locality where the pipe lies was being filled, cinders and hot slag (sometimes red-hot) were dumped within from 12 to 15 feet of the pipe, and an iron pipe now carries the hot drip from the rolls over and within 12 inches of this pipe. For five or six years the pipe was used only for fire purposes, and the water was found to be very warm whenever a hydrant was opened. Now, however, the water runs all the time to supply a drinking fountain. It remains to be seen whether corrosion is less active in the future than in the past.

It is very possible that the air which comes in contact with the moist pipe is (or was) such as to act upon the pipe more rapidly than ordinary air would. It appears that the locality has been, for a long time, the receptacle of drainage water containing much organic matter, and is even now freely used as a urinal. The decomposing organic matter beneath and in the filling, would give rise to carbonic acid and ammonia gases, both of which are corrosive agents.

Whether the air in the interstices of the filling differs from ordinary air, admits, of course, of being ascertained experimentally. At this season of the year I should not expect as much difference as in summer, when the warmer weather would make the decomposition of the organic matter take place more rapidly. However, I suggested to Mr. Borden a somewhat crude method by which samples of the air might be taken, and on three different days he took samples; those marked "E" are from a point about 15 feet east of the west line of the Nail Mill. Those marked "W" are from a point midway between the points A and B on the plan, where the corrosion was greatest. The results of the examination (for which I am indebted to Mrs. Professor Richards) are as follows:

* Br. Assoc. Rep. (1840), p. 256.

CARBONIC ACID IN 10,000 VOLS. AIR.

		Vols.
April 1, 1885	E.	4.32
	W.	4.99
April 3, 1885	E.	4.94
	W.	4.89
April 4, 1885	E.	4.15
	W.	4.95

Outer air usually contains about 3 vols. in 10,000, and ground air usually more than the samples above. The results are not, therefore, very convincing, but I should like to repeat the experiment in warmer weather.

Of the single suggested causes, I have looked with most suspicion upon the "grease" which comes from the rolls of the iron works, and which is evidently present in the slag and probably in the corroded portion of the pipe. Every one of several samples tried showed grease or oil, but as the pipes had been treated with coal tar and linseed oil, I cannot assert that the oily matter found was not derived from this source. It is well known that the greasy water from surface condensers is very corrosive to boilers, and this is partly due to the fact that the grease is decomposed by steam, and fatty acids are formed. I have not yet satisfied myself as to the existence of oleate (or other fatty salt) of iron in the corroded pipe, and this I should expect to find if the grease were the prime cause. I tested also the various samples of water for grease with negative results; but this of itself would prove little, as the samples were all taken the same day. Moreover, it appears that for several years the pipes were exposed to warm and, presumptively, greasy water much more freely than at the present time.

I must confess that one of the most inexplicable things to me is the insufficient protection afforded by the coal-tar coating. Mallet and other experimenters found that coal-tar laid on hot was one of the most protective coatings, and although there are some tubercules in the interior of this pipe, the coating seems to have been well applied. It is hard to believe that, in this case, an unprotected pipe could have decayed much faster.

The table on the next page contains the results of the chemical examination of the three layers of the corroded pipe and also of iron from the spigot end of one of the pipes. As the spigot was not from the identical pipe from which the corroded ring was cut, the comparison must not be pressed too closely, but it probably represents nearly enough the original iron. We should expect that as the corrosion proceeded, the iron would be partly oxydized and partly dissolved away as protocarbonate or otherwise, and that the carbon, the silicon, the phosphorus would accumulate to form a larger proportion of the mass. Examination of the figures in the table shows that the graphite, the silicon and the phosphorus do increase in amount from the center outward, and in almost identically the same proportion. It appears, however, that while the iron decreases in the same direction, it decreases much less rapidly.

Some surprise has been expressed at the lightness of the corroded material, and one chemist has suggested the theory that this may be due to the presence of metallic aluminum. There are several objections to this view. In the first place, it is quite unnecessary. A fragment of the corroded part of the pipe (including the "middle" and "outside" layer, as designated above) was found to have an apparent specific gravity of 2.33, bul it was very evident that the lightness was due in part to the fact that the material was very porous, and contained, therefore, a good deal of air. Moreover, as it contained oily matter, it was not readily wet by water. Small lumps heated in water to the boiling point and then cooled down gave a specific gravity of 2.73, and when the material was in the form of a moderately fine powder the specific gravity rose to 2.98.

If now, we take the mean composition of the corroded material (middle and outside layers) to be:

	Per cent.
Moisture	6.11
Silica	17.50
Sulphide of iron	1.04
Phosphoric acid	4.17
Graphite	12.10
Oxide of iron	53.25
Oil, water of hydration, hydrocarbons, etc.	5.83
Total	100.00

and then reckon the phosphate of iron as corresponding in composition and specific gravity with the native mineral dufreynite, and take as the specific gravities of

	Outside layer.		Middle layer.		Inside layer.		Spigot end.	
Moisture	.....	6.62	.....	5.61	.....	und.	und.	.....
Silicon	9.94	.....	6.41	.....	3.31	.....	1.77	.....
Silicon calculated as silica (SiO_2)	.....	21.30	.....	13.74	.....	7.09	.....	3.79
Phosphorus	2.20	.....	1.44	.....	0.69	.....	0.39	.....
Phosphorus calculated as phosphoric acid (P_2O_5)	.....	5.04	.....	3.30	.....	1.58	.....	0.89
Graphite	.....	14.75	.....	9.46	.....	und.	2.63	.....
Iron	33.73	.....	43.15	.....	72 97	.....	93.18	.....
Iron calculated as oxide (Fe_2O_3)*	.....	45.74	.....	60.77	.....	.....	.....	.....
Sulphur	0.41	.....	0.35	.....	0.19	.....	0.09	.....
Sulphur calculated as iron sulphide (FeS)	.....	1.12	.....	0.96	.....	0.52	.....	0.25
Copper	.....	0.22	.....	trace.	trace.	.....	trace.	.....
Manganese	0.53	.....	.....	und.	und.	.....	0.61	.....
Manganese calculated as oxide (Mn_3O_4)	.....	0.74	.....	.....	.....	.....	.....	.....
Oil, etc., before hydrochloric acid	.....	0.96	.....	0.08	trace.	.....	.....	.....
Oil, etc., after hydrochloric acid	.....	0.61	.....	.....	.....	.....	.....	.....
Non-graphitic carbon	.....	und.	.....	und.	und.	.....	0.77	.....
		97.10					99.44	

* After deducting the amount required for the sulphide of iron.

the other ingredients the observed specific gravities of the corresponding native minerals, we reach the following basis on which to calculate a possible specific gravity for our mixture:

	Per cent.	Sp. gr.
Water, oil, etc	11.94 say 12 0	1.0
Silica	17.50 " 17.5	2.5
Sulphide of iron	1.04 " 1.0	4.7
Graphite	12 10 " 12.0	2.2
Phosphate of iron	15.16 " 15.2	3.2
Oxide of iron	42.26 " 42.3	5.2

The specific gravity of such a mixture as this would be 2.63. This claims to be nothing more than a rough approximation, but it shows that knowing the composition and character of the substance, we need not be surprised at the low specific gravity.

Another reason why I cannot accept the aluminum theory is that, from our knowledge of the difficulty with which aluminum is reduced from its compounds and obtained in the metallic state, I cannot conceive how the reduction could take place when the tendency of all the constituents of the original iron is to become oxydized. No one would claim that this oxydation could be effected in the wet way by the reduction of aluminum compounds.

The third reason for rejecting the aluminum theory is that there is only the merest trace of aluminum present in any form.

Since this paper was read another sample of the corroded material has been submitted to partial analysis. This specimen came from near the bell end of the same pipe, the spigot end of which was taken as a sample of the original iron. The surface here showed the asphalt coating still remaining, and only two layers could be distinguished. The inner layer was not analyzed, but did not seem to be wholly unaltered iron; the outer layer was harder than in the specimen described above, although it could be reduced to a fine powder without difficulty. The results of the partial analysis were as follows:

	Corrosion. Bell end.	Original iron. Spigot end.
Moisture	3 87	Undet.
Oil, etc., extracted by ether	0.40	Trace.
Oil, etc., after hydrochloric acid	0.22	0.00
Iron	52.94	93.18
Graphite	7.93	2.63

THE THEORY OF GAS ENGINES.

From "The Engineer."

In the case now pending, Otto *v.* Steel, much importance has been attached to a paper by a French *savant*, M. Beau de Rochas, entitled "Nouvelles Recherches sur les Conditions Pratiques de plus Grande Utilisation de la Chaleur et en General de la Force Motrice." This paper was published in Paris in 1862. We give a translation of it, not only in order to make the course of events clear in the case of Otto *v.* Steel, but because it is really a very valuable contribution to the theory of heat-motor engines:

Combined gas and steam motor.—When we examine what takes place in the combustion chamber of the gas-fired boiler. we are struck with the enormous volume which gases raised to a high temperature attain. If the combustion, on the other hand, takes place at constant volume, the dilation will be replaced by an equally considerable accession of elastic force, and the return to the original pressure by means of expansion will give precisely the same volume at the same temperature as if the heating had originally taken place under constant pressure. It is directly evident from this that in the mere fact of combustion there ma be a production of power of an order of considerable greatness, and completely independent of that which would afterwards result from the formation of steam by the cooling of the burnt gases, from which we conclude that the complete utilization of the phenomena of combustion requires that we should at the same time profit by the elastic force which gases can directly acquire from combustion at constant volume, and the elastic force which they can subsequently communicate to steam by giving up to it their dilating heat, a heat which is identically the same as if they had been heated without producing an excess of elastic force over the surrounding pressures. This complete utilization would have been manifestly impracticable with the use of solid combustibles alone. It becomes infallible on their previous conversion into gases, which are themselves combustible. And such is the immense final result of the invention of gas furnaces, the priority in which belongs to Messrs. Thomas & Laurens, but in respect of which it is only fair to afford considerable recognition to the scientific labors of Messrs. Helman, in France, and Faber Dufaur, in Germany. We must henceforth, then, consider as essentially incomplete—and so consider from our knowledge of the cause—all gas engines alone and steam engines alone, and it is easy to demonstrate that the one is necessarily the normal complement of the other. The action of gases as vehicles of motive force assumes the previous starting of the motor apparatus, for precisely because gases exist already formed and cannot do work without expansion, they are incapable of setting themselves to work, and can only act as active agents into a system already in motion. It is for this reason there have never been, and there never will be, gas engines, whatever their principle, which can be applied to cases in which the starting requires more or less powerful or rapid effort without the simultaneous concurrence of some external force. Gas engines, pure and simple, are therefore, essentially engines of small powers. Steam-engines, on the contrary, are capable of the most powerful direct action, but at the price of an excessive expenditure of heat. That is, in effect, how M. Regnault expresses himself on this point—*Comptes Rendus*, April 18th, 1853: "In air-motors—allowance being made for exterior losses and for mechanical obstacles which may present themselves in practice—all the heat expended is utilized for working power, while in the best steam-engine the heat utilized in mechanical labor is not the twentieth part of the heat expended, and it is even much less in most casas." This normal inferiority of return is a certain sign that steam alone cannot be a truly economical agent for the transmission of work, but the very mechanism of its formation makes it the indispensable

starting agent. Such, then, is the proper use of steam, to be, if not the preponderating expansive power, at least the finger always ready to press the trigger. This proposition may appear in contradiction to certain facts which would tend to establish that it is difficult to obtain from gases a great power of expansion. The permanent gases appear, in fact, perhaps even more sensible than vapors to the various causes of loss of heat. But we must distinguish between normal losses and accidental losses, notably by dispersion. Permanent gases ought to be considered as vapors infinitely below their point of saturation, and it is impossible that they can restore in any case one particle of their specific heat, and it follows from this, they ought, in working, to cool at a much greater rate than vapors. But it is of little importance whether the curve of pressure falls more or less rapidly on expansion, if the useful effect is, in the end, more considerable. As for the accidental losses, if, in combining the gas-engine with the steam-engine, we arrange things in such a way that these losses are turned more especially to the profit of steam-raising itself, we have realized the maximum practical effect, for even if gases are really difficult to handle, it is chiefly by reason of their great dispersive power, and if the losses accruing under this head, already supposed as reduced to their best possible use in a corresponding production of steam, we have all the useful effect of the steam, as hitherto, plus that which we can obtain from the elastic force of the gas itself In conclusion, it is necessary to observe that among the necessary and rational conditions of transmission of force the first appears to be the very existence of a mass of superabundant heat, and the limit of practical utilization of this is manifestly arrived at when the quantity of heat necessary for the formation and maintenance of this mass is brought to its lowest point by disposing in their rational order the only physical agents which we can generally use, namely, fuel, air and water. This is the leading idea of the mixed gas and steam-motor, a natural consequence, also, of the application of gas furnaces to the heating of steam boilers. The simultaneous utilization of the expansive force of gas and steam will generally require the employment of two sets of cylinders, viz., those in which combustion is effected, and steam cylinders. The most simple arrangement will consist in making the in-draught of gas from the cupola, and of the fresh air necessary for combustion by the suction of the gas cylinder itself, and in forcing out, after their expansion the burnt gases in the steam boiler, the exhaust of the steam cylinder, will then serve most readily to diminish the cushioning of the gas cylinder by facilitating the expulsion of the burnt and cooled air out of the engine, at least unless we can find a more useful employment of the steam in condensing it. There being nothing requiring modification in the arrangement of steam cylinders, the practical use of which appears to have followed close upon their being perfected in each particular case, we will only occupy ourselves here with the designing of gas cylinders, the practice in which is much less advanced. We shall distinguish two general cases according as the gas to be burnt is taken at atmospheric pressure or is previously compressed.

Arrangement without previous compression.—Combustible gas and fresh air are drawn in during a portion only of the stroke of the pistons of the gas cylinders. These cylinders thus perform the function of suction bellows by drawing in air for the supply of the cupola. Taps and valves regulate the access and proportions of the two descriptions of gas. The mixture is effected at low temperature, in conduits arranged for that purposes, and ignition is produced by known processes. The volumes of the gas and steam cylinders are arranged in accordance with the expenditure of the two fluids. Nevertheless, the steam cylinders ought to be of themselves powerful enough to start the whole machine. It could then be arranged, according to circumstances, that the steam-throttle valve might be entirely opened for the purpose of starting, and normally more or less closed during working. The high temperature produced in the gas cylinder by direct combustion would be a cause of speedy destruction of the machine, if the walls were not maintained at a very low relative temperature. This low temperature would be an energetic cause of cooling in the gases, if it could

not be met by other arrangements. But there will always be only a very slight drawback from direct utilization, if the heat thus dissipated gives return in producing steam. The gas cylinders, as well as their frames, will therefore be surrounded by water, and placed, by means of their exterior surfaces, in communication with the boiler in such a way as to ensure the circulation of the water and the creation of steam. The elevation of temperature, even if very great, would otherwise cause no sensible inconvenience with the walls maintained at a constant temperature. It must be understood, in fact, that the metal walls, even though we suppose them to be very thick, can always transmit the total heat furnished to them without their temperature at the point of contact with the hot air being ever able to rise to an appreciable extent above that of the boiler. The coating of air in immediate contact with the wall will always then be in instantaneous equilibrium of temperature with it. The propagation of the cooling through the gaseous mass will otherwise always proceed in accordance with the laws of dispersion—that is to say, in proportion to time and to distance. An analogous action takes place in the piston faces, in the castings in front, and in the piston rod, for these surfaces incessantly exchange radiated heat, and cannot, therefore, differ sensibly in temperature. The temperature of the gaseous mass, for a given position of the piston, will be highest then in those parts furthest from the cool walls. It will at first only vary slowly, and will only commence to fall really suddenly at a small distance from the same walls. The conditions of procedure, then, will not be sensibly different in gas and steam cylinders; there will be nothing to change essentially in the pistons, stuffing-boxes, &c., the lubrication of which can be effected by ordinary processes. The work produced being in proportion to the pressure produced by the combustion, it is desirable to preserve the highest possible value of this factor, for we can always regulate the strength of the machine accordingly. Besides, it is the special advantage of gas-engines that they admit, without danger, of pressures in the cylinders in which combustion takes place which would be unattainable in a steam boiler. Now, we attach in practice a greater and greater value to increase of pressure, and with reason, for in pressure alone lies not only the cause of motion, but, above all things, the utilization of force. Pressure being in inverse ratio to the temperature before ignition, it is important that the gas from the cupola should be, as far as possible, cooled before its entry into the cylinder. With this object the boiler will be furnished with two systems of tubes, one on the side of the cupola, the other on the side of the exhaust, in such a way as to form two interior compartments, separated, at least, by a partition impermeable to air. The fireproof jacket of the interior cylinder will be done away with as useless in the case in question. Consequently, the combustible gas will be drawn from the first compartment, after having traversed the tubes in it, and being brought to the temperature of steam, or thereabouts. The burnt gases will be driven into the second compartment, and discharged by the chimney after being equally cooled. The condition of things of which we are treating requires that the steam should be of the lowest pressure possible. It must not descend, however, below the point at which the temperature will be insufficient to cause the precipitation of the calcareous salts in the purifying apparatus, which is in this case absolutely indispensable. The pressure in the boiler, therefore, should never exceed six or seven atmospheres.*

The pressure is, moreover, proportional to the temperature of combustion. This temperature will be highest when we only admit the amount of fresh air absolutely necessary for combustion. It is to these particular conditions of air supply that the maximum effect of the engine will evidently correspond. The effect will diminish in proportion as, in accordance with the work required, we admit a greater or less excess of air, or, what comes to the same thing, we more or less close the regulator of the cupola. But even in the case in which the duty of the engine is smallest, it is still desirable to work with the maximum useful effect. Now, for a combustion tempera-

* Here there is, however, a question of maximum for the total work of the gases and of the steam, which we can only indicate in passing.

ture corresponding to a given proportion of combustible gas, and consequently to a known pressure after combustion, there is a certain length of suction — we should say "inlet" in case of a steam cylinder—for which the work developed in the cylinder is a maximum. The variation in amount of suction answering in each case to the maximum of work, being confined within narrow limits, the use of a slide will perfectly suffice to obtain the greatest variation in the yield of combustible gas. The arrangement, therefore, of the gas cylinders in the case in question can be made in the simplest manner with a common slide-valve, modifying, it is always understood, the forward and backward movements of it, to meet this particular requirement.

Arrangement with previous compression.—The arrangement before described appears certainly the simplest that could exist. It will perhaps be the only one applicable to locomotives. Then the increase of utilized power resulting from it will certainly be clear gain and without any doubt out of proportion to the cost of setting up. But the true conditions of the best employment of the elastic force of gases, at least its most important conditions, are not there observed, and simplicity is, perhaps, only acquired at the expense of utility. These conditions, in fact, are four in number — (1) the greatest possible cylinder space with the least possible exterior surface; (2) the greatest possible quickness of action; (3) the greatest possible expansion, and (4) the greatest possible pressure at the commencement of the expansion. The dispersive power of gases, so favorable to the use of boiler tubes, is evidently, on the contrary, an obstacle to the utilization of elastic force developed in the gaseous mass. Now, we have seen that in the case of boiler tubes the efficiency —that is to say, the heat transmitted— was proportional to the diameter of the tubes. The loss would, therefore, be in inverse ratio to the diameter in the case of cylinders. But that is only applicable to cylinders of very small diameter, and the loss decreases in reality in a more rapid proportion than the diameter increases. Therefore, an arrangement which, for a given consumption of gas, will give cylinders of the greatest diameter will be that with which the greatest direct utilization of heat will correspond in this respect. We equally conclude from this that, as far as possible, we must only employ one gas cylinder in each separate machine. But dispersion depends also upon time. Cooling, then, will be as much greater, other things being equal, as the working pace is slower. Now, a more rapid working pace seems to imply as a consequence cylinders of a smaller volume; but this contradiction disappears when one reflects that the length of stroke is not necessarily related in an invariable manner to the cylinder volume for a given expenditure. In like manner as for the elastic force of steam, the utilization of the elastic force of gases requires that the expansion should be the most prolonged possible. In the arrangement above described there is a maximum of expansion for each particular case. Thus the effect is necessarily limited. The advantage, therefore, rests with an arrangement which will permit of giving back to the machine that which we may call the free play of the expansion, that is to say, the power of expanding so far as we may think it convenient within the limits only imposed by the nature of things. Finally, the utilization of the elastic force of gases still depends on one element which is entirely their own, but which is at bottom intimately connected with the utility of prolonged expansion. This element is compression, which should be the greatest possible for the greatest effect. It can be easily seen that we are dealing here with heated expansion obtained after cold compression, which is a way of prolonging the expansion in some sort inverse to that which consists in causing a vacuum, a way to which steam could not adapt itself, it being always understood that all compression causes inevitably an equivalent condensation in such a way that, even supposing steam to be combustible, instantaneous heating would be rendered impossible by reason of it. We can, therefore, theoretically get as indefinite a utilization of the elastic force of gases by compressing them indefinitely before heating, as we can get an indefinite utilization of the elastic force of steam by indefinitely prolonging expansion. But practically we soon attain an impassable limit. It is that at which the raising of temperature due to previous compression brings

about spontaneous ignition. In fact, in their continuing compression we shall only recover from the expansion up to this same point the work furnished by compression, less the loss occasioned by all useless action. There, then, is the limit imposed by the nature of things, and the final advantage in respect of utilization will rest with an arrangement which will permit of its attainment. The question being thus propounded, the sole arrangement really practicable consists evidently in forthwith employing but one cylinder, so that it is the largest possible, and further in reducing the resisting movements of the gases to their absolute minimum. Then, and for the same side of the cylinder, we are naturally led to execute the following operations, in a period of four consecutive strokes: (1) Suction during an entire stroke of the piston; (2) compression during the following stroke; (3) ignition at the dead point and expansion during the third stroke; (4) forcing out of the burnt gases from the cylinder on the fourth and last return stroke. The same operations being reproduced on the other side of the cylinder in a similar number of strokes of the piston, there results a particular sort of single-acting machine, we might say of *half-power*, but which evidently satisfies the condition of largest possible cylinder, and at the same time that condition, which is still more important, of previous compression. We see at the same time that the velocity of the piston is the greatest possible in relation to the diameter, since we do in a single stroke the work for which we should otherwise take two, and we evidently cannot do more. The temperature of the gas coming from the cupola is appreciably constant. That of the external air relatively varies only between narrow limits. Then the initial temperature of the mixture at the moment of the suction into the cylinder will also be appreciably constant. It will therefore be possible to determine the limit of compression at which ignition would become inevitable, and to arrange the machine accordingly. We shall thus constantly have the absolute maximum effect for each proportion of combustible material. We shall at the same time be freed from the intervention of electricity, for, the starting being effected by the action of the steam, the gases need never be introduced until the speed shall have become sufficient for ignition to be produced with certainty. In all cases compression will favor instantaneous ignition by helping complete mixture, and in raising the temperature. In fine, and with an initial temperature corresponding to a pressure of five to six atmospheres in the boiler, ignition will be spontaneously produced with a degree of compression reaching to about a fourth of the original volume—at least, if we neglect the effect of dispersion. Then the pressure after ignition would attain barely thirty atmospheres, and as we are dealing here with the case in which combustion is effected without excess of air, the pressure would necessarily be lower in all other cases. It is, therefore, probable that in many cases we can really attain the absolute limit of utilization. To sum up, while manifestly lending itself, in the completest possible manner, to the utilization of elastic force developed in the gaseous mass by combustion under constant volume, the arrangement now in question is not less simple than the preceding one—at least, unless we consider as a complication the necessity, or rather the convenience, of employing in some cases distribution by clack valves. This distribution is generally the most advantageous, and there is nothing to prove that it is not generally applicable even to locomotives, and, above all, to the case in question.

THE DIAMOND DRILL IN NEW SOUTH WALES.—The diamond drill is doing good work in discovering or proving coal in various parts of the colony, the most important recently discovered being a seam of good coal, some 12 feet thick, in the parish of Heathcote, 28 miles from Sydney on the Illawarra Railway. The drill pierced this seam at 847 feet below the surface. Hitherto all attempts to find coal near Sydney have been unsuccessful. When the Illawarra Railway reaches Heathcote it will be possible to send coal from the mine to Sydney by rail at a very moderate cost, and vessels will be able to coal at Port Jackson.

WATER SUPPLY.

By WILLIAM POLE, F. R. S., M. Inst. C. E.

A Lecture delivered before the Institution of Civil Engineers.

Mr. President and Gentlemen,—It was with considerable diffidence that I undertook to deliver this lecture on Water Supply. You all know that we have in our Institution some veterans who have acquired world-wide fame in this department of engineering; and it was not till I had been assured that there was no hope of getting any of them to undertake it that I would listen to the application. I am not, as they are, renowned for the construction of water-works; but it happens that, during almost the whole of a long professional life, I have been occupied, more or less, in the study and discussion of matters connected with water supply, and I suppose it is on this account that the Council have done me the honor to apply to me.

And, in reality, my task is not a very difficult one; for, thanks to the great ability and long experience of the masters of the craft, the modes of effecting water supply have been pretty well settled. My chief duty is to give a very general view, without much detail, of the principles and practice that appear to have been established in this matter, and if I can succeed in doing this clearly, it is all I can desire.

The prospectus of these lectures gives the general title of "The Theory and Practice of Hydromechanics." I have little to say about theory here, as the problems affecting water-supply works are chiefly the same as for mechanical and structural engineering generally.

In regard to the theory of hydrodynamics, I may refer you to an able article lately published in the "Encyclopædia Britannica," by a Member of our body, who has made this subject specially his own, Professor Unwin; and as you will shortly have the pleasure of hearing a lecture by this gentleman, he will probably give you some remarks on the point. I will only say a word as to the special problem of the flow of water along channels of various kinds.

There are certain simple and well-known formulæ and tables which, by long experience, have been found fairly suitable for ordinary purposes. But later researches have shown that in many points they require amendment when a greater approach to accuracy is desired. These researches were made some years ago, by two French engineers, MM. D'Arcy and Bazin; and the points they chiefly laid stress on were two:

In the first place, it had been usually assumed that the retarding force of the friction was independent of the nature of the surface of the channel. This was found to be an error, different materials requiring different coefficients.

And then, secondly, it was discovered that the relations between the velocities of the current at different parts of the section had not been correctly determined, and had values varying greatly under different circumstances.

I am not going further into these matters; they can easily be referred to if required. And having said this, I will proceed to the more practical views of water supply.

In the admirable Introductory Lecture we have heard explained the general phenomena by which the great element, water, is delivered on the earth for our use. We have now to enter on what is more strictly the province of the engineer in regard to water. We have to show how the stores of this invaluable substance can be, and are, made available for the use and convenience of man. This is done in many ways. The engineer has to provide and distribute supplies of water for the food and the various necessities of congregated populations. He has to make available the ample natural stores of mechanical water-power. He has to direct and control the natural flow of surface waters, by operations of drainage and river regulation. He has to take advantage of the fluid mobility of water, by using it to form highways of minimum traction in inland navigation. He has, moreover, to design floating vessels to

ravel upon water. And he has to provide for the safe and convenient communication of such vessels with the land, by harbors, docks, and piers.

All these works in the aggregate, with their almost infinite expanse of detail, constitute the great branch of our profession called hydraulic engineering; and this will form the subject of the remaining lectures of the present course.

But before I enter on my humble share of the work, I should like to mention an interesting historical fact, which I think is not generally known, namely, that it is especially to hydraulics that civil engineers are indebted for their origin and existence as a separate and independent profession.

The term "engineer" was originally applied to military men. Building-works in civil life were constructed by the architect, who in all ages has been a well recognized practitioner.

A century or two ago, however, a new and peculiar demand arose in this wise. The great rivers in the north of Italy had relapsed, by neglect, into a very bad state, giving rise to disastrous inundations. The nation became alarmed, and the most learned scientific men of the day were consulted as to what should be done. This gave rise to a series of valuable theoretical and practical studies, which are of great historical interest, as having formed the basis of hydraulic engineering. The knowledge spread rapidly throughout Europe, and gave a great impulse to hydraulic operations generally.

But there was now a want of competent men to execute them. The architects found these new studies foreign to their own proper business; and so a new class of practitioners sprang up for hydraulic works; with which soon became associated other works of analogous character. Such a class required a new name, and this was easily found. It was noticed that the kind of work undertaken by these new practitioners corresponded to that allotted to the engineers of the military service; and the new profession adopted the same title, prefixing, however, the epithet "civil," to indicate that they were civilians, and so to distinguish them from their military brethren.

Hence the origin of the present term, "civil engineer," an origin which, as I have said, was due entirely to the cultivation of hydraulic science, and its application to works of hydraulic construction.

The expression, "water supply," in its general sense, may have a wide interpretation. It may refer to supplies of many kinds, and for many different objects. But there is one kind of water supply which stands pre eminent and before all others, namely, the supply to the inhabitants of towns. It was this that was probably in the minds of your Council when they drew the title of this lecture, and I shall not err in directing attention specially to it.

I need hardly enlarge on the value of water. I suppose it is the most important natural substance known, and the most indispensable for maintaining the present order of things in organic life. The old Greek sentiment, "Αριστον μεν υδορ, was a natural prompting; some ancient philosophers supposed water to be the primordial element of which every living being was composed; and this is so far true, that water forms a very large part of the bodies of plants and animals, and constitutes, either simply or in combination, the greater portion of their food. The need of water for the life, health, comfort, and occupations of mankind, is patent to everybody; and hence the provisions for a due supply of it, of proper quality, in ample quantity, and in a convenient manner, become an absolute necessity of civilization.

History.

In the earliest times people helped themselves from the nearest brooks or streams. But this hand-to-mouth process was only available in certain places; and as it was observed by unmistakable signs that the superficial strata of the earth often contained water, the idea occurred to some ingenious person that this water might be got at by simply making a hole in the ground, or, in other words, "sinking a well." Wells are mentioned as sources of water supply in the oldest records we have, and the art of sinking and working them had arrived, in early ages, at great perfection.

But still even wells could not be got everywhere, and as populations increased, some further extension of water supply became necessary. The simplest plan of meeting this want was to carry the water in suitable vessels from the stream or the

well where it was found to the places where it was required. And, primitive as this plan appears, it has lasted into quite modern days. I recollect, when I lived as a boy in a large English town, seeing water carried about for sale, in cans with a yoke, as milk is often carried here; and even a few years ago, being in a fashionable watering-place for my health, I was advised by the local doctor not to use the town supply, but to drink the water of a neighboring spring, brought round in a barrel on wheels every day.

But the more appropriate device soon presented itself of conveying water from distant sources by means of conduits, slightly inclined, so as to allow the liquid to flow along them by its own gravity. This was, indeed, only a direct artificial imitation of natural streams. It is very old, and is mentioned by Homer. It began in leading streams along the surface of the ground; but it ultimately developed into the supply of towns by the ancient aqueducts with which you are all acquainted, and which culminated in the magnificent water supply of the Eternal City.

These aqueduct-conduits usually terminated in public fountains within the town, from which the inhabitants could, without much trouble or inconvenience, get the water carried to their dwellings. Everybody who has been in Rome has admired the fountains there, and they are very common in continental cities generally.

The next great step in municipal water supply, namely, that of delivering the water into the houses of the inhabitants, is of comparatively late introduction. It depended on a considerable degree of mechanical advancement; for to carry out such a system it was necessary to convey the water in pipes under pressure. There is no doubt that pipes of earthenware, of wood, and of lead, were used by the Romans to some extent, but they were very imperfect, and nothing existed in the shape of such fitting as would be necessary for house supplies. The first application of the house supply that I can hear of was in London, brought about by the historically celebrated waterworks of Peter Morice, the Dutchman, established at London Bridge, in 1582. Here water-wheels were erected which pumped the water from the Thames, and forced it along pipes laid through the streets, to the places where it was required; and it is clearly stated by the well-known antiquarian authority, Stowe, that "the Thames water was conveyed into men's houses by pipes of lead."

When this convenient system was once established, it was easily seen that the more ancient conduit supplies might also be adapted to it, by bringing the water into a reservoir at a high level, the hydrostatic pressure from which would answer the same purpose as the pumping pressure in the former case. This was done in the New River supply, brought into London in 1613.

Here, therefore, we have the two types of pumping and gravitation supplies on which all succeeding works have been modeled, with only improvements in detail.

The original London street pipes were, if small, of lead, and, if large, of wood. About the middle of the eighteenth century cast-iron pipes were used, but their high price prevented their general adoption for a long time; it was not till about 1810 that this material may be said to have come into common use, and it was only after that date that the water supply of towns could take any great development. This development did follow, in the attainment of a higher pressure, and generally a better and more ample supply, and the improvements have been continually progressing to the present day.

Before considering the various modes of effecting the water supply in towns, it is necessary to say a few words on two points of a general nature which bear alike on all modes of supply. These are the quality of the water, and the quantity of it which is likely to be required.

Quality of Water.

The quality of water to be supplied to a town is a matter of great importance. This is a subject properly belonging to chemistry, and the aid and advice of a professional chemist must always be called in upon it. But still, any engineer concerned in a water scheme would be at a manifest disadvantage, if he did not know enough of the matter himself, to enable him at least to form a preliminary judgment on the sources of supply.

Rain-water, as distilled in the clouds,

may be considered as practically pure; but it seldom happens that it can be collected and stored without having undergone some contamination. However directly we may attempt to catch it, it will be liable to take up some foreign ingredient from the collecting surfaces, and if it percolates through the earth to springs and wells, it will gather a still greater amount of foreign matters.

The impurities taken up may be classed under three heads:

I. Substances mechanically suspended in the water.

II. Mineral substances chemically dissolved in the water.

III. Dissolved organic impurities.

This classification is not strictly definite in a chemical sense, but it is convenient as regards the importance of the impurities in the view of the engineer.

I. *Suspended impurities* are chiefly found in the water of rivers and streams. They come from the water washing over earth, clay, mud, sand, refuse, etc, the finer particles of which it carries away, and holds in mechanical suspension. "Dirty water," "turbid water," "muddy water," are only other names for water containing matter in suspension. This kind of impurity is of the least importance to the engineer, seeing that it admits of thorough removal by easy means. Two operations are used for this purpose, viz., subsidence and filtration.

Subsidence is simply allowing the water to rest, when the grosser and heavier particles, which are only kept in suspension by motion, will fall down. Everybody who has seen the Lake of Geneva will remember that the Rhone, which flows in at the head in a muddy stream, issues out at Geneva as clear as crystal. The lake is simply a vast subsiding reservoir.

It is impossible to make ordinary subsiding reservoirs as effective as Lac Leman, but they will do a great deal of good, and down to the year 1829, they were the only means used for purifying water supplies. The defect of them is, that some of the suspended matters are so light that they will not subside without much more time than can be allowed, and to remove these matters, an additional process is used, namely, filtration.

This is exactly analogous to ordinary filtration, the water being passed, at a slow rate, through a porous material, of such fine texture as to stop the suspended particles, and allow only the clear fluid to pass through.

This contrivance, as applied to water supplies on a large scale, originated in London in 1828. A Royal Commission had reported that the Thames water supplied to the metropolis was very dirty and objectionable, and the late Mr. James Simpson, the engineer of the Chelsea water-works, determined to try what could be done to improve it. It was known that fine sand was a good and efficient material for effecting filtration; but the difficulty was how to apply it on a large scale, so as to render the cleansing of the filter reasonably practicable. It occurred to him that if the water was allowed to pass downwards through a bed of fine sand, held up by underlying layers of coarse gravel and stones, the dirt would not penetrate into the mass, but would be stopped at its upper surface, and in this way the whole cleaning operation necessary would be to scrape this surface off to a slight thickness, and, when it had become too much diminished, to put fresh sand on. The first water-works filter on this plan, of one acre area, was set to work by Mr. Simpson, at the Chelsea water-works, in 1829. It was found to work well, and has furnished a model, with scarcely any material change, for all subsequent time.

The filtering action has been above described as purely mechanical, *i. e.*, as arresting the suspended particles, and nothing further. But careful observations on the process have lately led to a belief that it exercises some chemical purifying action on the dissolved organic matter. The nature of this action is at present obscure. It is supposed, however, that some kind of oxydizing process may be encouraged in the passage through the pores of the material; and it is certain that, by the expedient of intermitting the filtration, so as to allow of the aeration of the material, this effect may be rendered much more active.

It is important that in ordinary sand filtration the process should not be hurried. Slowness promotes good purification, and the rate of passage through can be regulated by the head of water over the sand. The result of experience with London water is, that the rate of pass-

age should not exceed 2½ gallons per hour through each square foot of area. At this rate each million gallons a day will require 16,700 square feet of filter at work, and allowance must be made for one filter bed being always out of use for cleaning.

In some peculiar cases, special materials have been used instead of sand. It has been found, for example, that certain compounds of iron have a remarkable effect in destroying organic matter. The town of Wakefield has been for a long time supplied from the River Calder, the water being so impure. that a letter written with it was published by the Rivers Pollution Commissioners. Yet the unwholesomeness of this was checked by filtration through a magnetic carbide of iron. Another case has been lately described to this institution by Mr. Wm. Anderson, where the water supplied to Antwerp was purified by Bischoff's spongy iron in the same way.

The two operations, subsidence and filtration, are usually combined, the advantage being that the previous extraction of the grosser particles gives the filters less to do, and allows them to work longer without cleaning.

II. But, though the water may be clear and bright, it may contain a different class of impurities, namely, *mineral substances chemically dissolved* therein, that cannot be removed by filtration.

Such dissolved matters exist in water sometimes in great extent and variety, forming what are called mineral or medicinal waters. These, however, are altogether exceptional; there is practically only one substance which affects water likely to be used for town supplies, and that is lime. Calcareous rocks occupy, it is said, four-fifths of the earth's surface, and as their material is, to a certain extent, soluble, the waters percolating through them take lime up in their passage. Hence, lime is found largely in wells and springs, and as superficial streams are almost always fed partially by springs, rivers contain lime also. The river Thames, for example, after perfect filtration, contains about 15 to 20 grains of solid matter in solution, which is almost entirely composed of salts of lime.

These salts communicate to the water the peculiar quality called *hardness;* soft water makes a lather freely, but hard water has a disposition to decompose or curdle soap, by the combination of the lime with the alkali.

There has been a great deal of discussion as to the comparative merits of hard and soft water for town supplies, and the subject was thoroughly investigated by the Royal Commission on Water Supply in 1869, to which I had the honor of being secretary. I may give you, in a few words, the result of their inquiries.

There are two uses of water to be considered—for drinking, and for washing and manufacturing purposes.

For dinking, there have been contradictory opinions as to the effect of hard water on health. Some say it causes calculous diseases; others say it promotes the formation of a healthy bony frame. But, when the evidence is examined, there is no reason whatever to suppose that a moderate hardness, like that in London, is in the least degree prejudicial.

And it has advantages in many respects; the water is pleasant to the taste, and by its less solvent power it is free from action on lead, which is often dangerous with very soft water. It is also less absorbent of gases and organic impurities, and it keeps better.

For washing and manufacturing purposes, however, the advantages of soft water are undeniable, and in towns where the uses of water for these purposes largely predominate, every effort should be made to procure a soft-water supply. Glasgow and Manchester are striking examples of how this may be done; and it is fortunate that the great manufacturing districts of England are so situated as to render soft-water supplies easily available. But from the great prevalence of the limestone formations, this is not possible everywhere; and where, as in London, a supply of moderate hardness is close at hand, it is a comfort to know that it may be used without material disadvantage.

I say of *moderate* hardness, but it often happens that the hardness is not moderate. The water from chalk wells, for example, sometimes contains 30 to 50 grains of lime-salts per gallon, when the use of the water may become very troublesome.

But nature has provided a remedy for

this, inasmuch as such water may be easily softened. The salts of lime are generally carbonates and sulphates, the former predominating. Now, carbonate of lime is very slightly soluble in pure water, only to the extent of about two grains in a gallon. The reason why natural water often contains so much more is the presence of free carbonic acid, which acts as a solvent, and enables the water to take up the extra quantity.

If, therefore, we can, by any means, drive away this carbonic acid, the superfluous carbonate of lime will be precipitated, and the water will be softened.

This may be effected in several ways:

1. By exposure of the water to the air, when the carbonic acid flies off spontaneously. Open channels conveying very hard water are often found to collect deposit from this cause, a striking example of which may be seen in the celebrated ancient aqueduct of the Pont du Gard, near Nismes. Stalactites and stalagmites in limestone caverns are formed in the same way, as are also the deposits in what are called petrifying springs.

2. By boiling. Every washerwoman knows that hard water may generally be softened by boiling, which drives off the carbonic acid rapidly. The deposit in boilers, so well known and so troublesome, is a result of this action. Many calcareous waters contain other salts of lime besides the carbonate, and these boiling will not remove. Hence it is customary to speak of the *temporary* as contrasted with the *permanent* hardness, the latter being the hardness which remains after boiling.

3. Another way of treating hard water is by adding simple lime in its caustic state. This seizes the free carbonic acid in the water, forming a carbonate, when both this and the carbonate already in the water are precipitated, and may be removed. It is curious that the hardness of water, which is due to lime, should be diminished by adding more lime; but the explanation is very clear.

This softening process, by means of lime, is due to the late Dr. Clark, of Aberdeen, who urged its adoption very warmly. In 1850 I assisted, under his direction, at some trials at the Chelsea water-works, to judge of its applicability to London water. We found it could easily be done, but it was expensive, and the general opinion was that the advantage was not worth the cost.

It has, however, been successfully applied elsewhere. In the same year Mr. Homersham adapted it to some large print works, and he afterwards put it in practice at Plumstead, at Caterham, and elsewhere. One of the latest and most successful applications has been made by Mr. Bateman at the Colne Valley Works, near Watford. The water, which comes from chalk wells, has naturally about 18 to 20 degrees of hardness, and is softened down to 5 degrees.

Some modifications of this softening process have lately been contrived. The most important one has been devised by Mr. Porter, with the view of doing away with the deposition in reservoirs, which is not only expensive, but takes a long time. He agitates the mixture, so as to produce quickly and thoroughly the necessary chemical change, and then passes it through a filtering press, which retains the precipitate, and allows the clear water to be forced through. It is also worthy of mention that Mr. Hallett, mayor of Brighton, has shown that by very simple and inexpensive apparatus a softening process may be adopted in private houses, wherever thought desirable.

III. The third kind of impurity is *organic impurity*, and this requires very careful consideration. But it will be convenient to postpone the remarks upon it till we come to speak of river supplies, in which it chiefly prevails.

Quantity of Water Required.

We now come to the other preliminary point. Before an engineer can take proper steps for the supply of a town he must form an estimate of the quantity of water he will require.

The water consumption in a town varies according to the occupations of its inhabitants, and the nature of the industries carried on, as well as, in some degree, on the habits of the people in regard to the use of water.

The quantity actually required for domestic consumption, including a fair allowance for general household purposes, for water-closets, and for ordinary ablutions, is probably not more than about 10 gallons per head per diem. But in addition to domestic consumption, supplies have to be provided for gardens and

stables, manufacturing and trade purposes of many kinds, baths and washhouses, public fountains, watering streets, flushing sewers, and extinguishing fires. The quantity for these purposes will vary considerably, say from 5 to 10 or more gallons per head per diem.

As a general rule, however, if the town contains nothing likely to make the consumption abnormal, it is usual to estimate that about 25 gallons per head per diem will be, or at least ought to be, a sufficient supply for all purposes.

I say ought to be, because there enters into this question a very important element, namely, waste. I shall have to speak about this hereafter, but I may say here that as a general principle the supply of more water in a town than is reasonably required for the health, comfort, and occupations of its inhabitants, and for the general sanitary public requirements, is an evil, and ought to be discouraged and repressed. Water is a very expensive thing to provide, and its excessive use not only wastes money, but does positive mischief by increasing the difficulty of carrying it away. An engineer, therefore, in designing water-works has a right to anticipate that reasonable care will be exercised to keep down the consumption to what is actually necessary.

At the same time, he must not stint his preparations; for in designing works for water supply, provision ought always to be made for increase of population. There are few towns of importance that do not extend their limits from year to year, and the cases where difficulty has occurred, from insufficient water provision being made for these extensions, have been frequent and troublesome.

It is important to remember that the consumption is not uniform. It has a considerable fluctuation at different hours of the day, and also at different parts of the year.

The daily fluctuation is caused by the variations in the demand for water at different hours, which is very considerable. The following table is the result of observations carefully taken under the direction of Mr. Ayris, who has kindly allowed me to make use of them for this lecture.

It is not easy to account for all the irregularities, but the general result is that, as might be expected, the consumption in the day time much exceeds that during the night, amounting at one time to above twice the average rate. This is about 10 A. M., when the domestic use of water may be supposed to be the most active.

PROPORTIONATE CONSUMPTION OF WATER AT DIFFERENT HOURS OF THE DAY IN A COUNTRY TOWN OF ABOUT 50,000 INHABITANTS, SUPPLIED UNDER THE SYSTEM OF CONSTANT SERVICE.

AVERAGE OF THE SIX WORKING DAYS.

	Proportionate Consumption in the Hour, the Average over the whole day being 100.
From 6 to 7 A. M.	104
" 7 " 8 "	193
" 8 " 9 "	128
" 9 " 10 "	215
" 10 " 11 "	161
" 11 " 12 "	122
" 12 " 1 P. M.	104
" 1 " 2 "	102
" 2 " 3 "	166
" 3 " 4 "	130
" 4 " 5 "	85
" 5 " 6 "	74
" 6 " 7 "	102
" 7 " 8 "	78
" 8 " 9 "	81
" 9 " 10 "	61
" 10 " 11 "	55
" 11 " 12 "	54
" 12 " 1 A. M.	66
" 1 " 2 "	52
" 2 " 3 "	74
" 3 " 4 "	52
" 4 " 5 "	65
" 5 " 6 "	74

The fluctuation in the consumption at different periods of the year will be shown by the following table, taken from Colonel Sir Francis Bolton's published Reports:

CONSUMPTION OF WATER IN LONDON DURING EACH MONTH OF THE YEAR 1883.

	Millions of Gallons per Diem.
January	133.5
February	130.8
March	132.9
April	139.0
May	143.6
June	159.5
July	159.1
August	159.8
September	154.1
October	146.5
November	142.7
December	138.6
Mean of the year	145.0

This shows an excess, over the average, of about 10 per cent. in the hottest

months, and a deficiency of about the same in the coldest.

Taking these two tables together, it will be seen that it is necessary, in all towns on constant supply, to provide carrying capacity much larger than is due to the average consumption. For example: suppose the average consumption over the whole year to be 1,000,000 gallons a day, then the average in the summer months will be 1,100,000 gallons. And in some hours of each day in those months the consumption will be at the rate of about 2,350,000 gallons per day, for which the mains must accordingly be prepared.

General Sources of Water Supply.

I now go on to speak of the various modes of obtaining water supplies. There is only one original source, rain; but there are several varieties in the modes by which the rainfall is made available. These are:

1. *Direct Collection.*—We may catch the rain-water as it descends close to the places where we want it, storing it up in suitable receptacles.

2. *Gathering Grounds.*—We may choose a surface of land, and collect the rain-water falling thereon.

3. *Rivers.*—We may take water by pumping from a river of sufficient magnitude, flowing along low ground.

4. *Wells or Springs.*—We may draw upon the stores of water contained in subterranean strata, by sinking wells; or we may collect the same water as it issues spontaneously in springs.

We may say something on each of these plans.

Direct Collection of Rainfall.

First, we may catch the rain as it descends, on the spot where it is wanted. A rain-water butt, collecting the rain from the roof of a house, by gutters and pipes, is a very common thing; and the same plan is often advantageously carried out in large isolated establishments, such as gaols, unions, asylums, etc.*

In Venice, the greater part of the water supply of the city is obtained in this way. Many people will recollect two handsome artistic well-curbs in the court of the Ducal Palace. These are openings into underground reservoirs made to receive and store the whole of the rain that falls on the buildings; and there is an ingenious arrangement by which the water is made to pass through a filter before it gets into the well.

But it is in India and other tropical climates that the direct collection of rainfall has the widest application. In these places a very large quantity of rain descends during the monsoon, *i. e.*, four months of the year, whereas during the other eight months not a drop falls. Rivers are only available in their immediate locality, streams become in the dry season mere sandy beds; wells are only locally and partially efficient, and the great trust is in the system of tanks. These are open excavations made in the ground in great numbers and often of large size, which become filled by direct rainfall during the monsoon, and store up the water for use during the rest of the year.

Gathering Grounds.

But the more common way of making a direct appropriation of rainfall is by collecting it on the surface of a tract of land, which is called a gathering ground.

To illustrate how this is done we will imagine a tract of land lying high in a hilly district, and on which a fairly large quantity of rain falls. By reason of the natural slope of the various portions of this area, the water will run off it in little rills and rivulets, which will ultimately combine into one principal stream, draining the whole area. Hence, by taking possession of, and utilizing this stream, we in reality collect and utilize the rain-water falling over the whole of this drainage area.

This is done by forming a *reservoir* upon the stream in question. The stream will naturally flow in a little valley, and, by choosing a convenient place, and constructing an embankment across this valley, the waters of the stream will be dammed back and impounded in the trough of the valley above the embankment, and so will form a reservoir, containing a store of water. This store is made available for the supply of a town, by simply laying down a conduit from the reservoir to carry it to the place where it is required. When the reservoir

* 1,000 square feet of horizontal roof surface, catching 24 inches of rain per annum, will, if none of the water is lost, yield 34 gallons per diem.

is full, the superfluous water will overflow by a waste-weir and conduit (called a bye-wash) down to its original channel.

This mode of obtaining water supplies is very common in hilly districts, and numbers of large towns, particularly in the manufacturing districts of Yorkshire and Lancashire, are supplied in this way.

The formation of large reservoirs of this kind is a very responsible and difficult thing, only to be undertaken by engineers of great experience and sound judgment. The first object is to secure the absolute safety of the dam, seeing the frightful consequences that must ensue if it should give way, suddenly letting loose such an enormous mass of water, from a great height, down upon the country below. When the reservoir is full the pressure upon the dam is very great, and although, considered as a mass, it may be stable enough, yet the water by penetrating among its loose materials may gradually endanger its cohesion; or the natural ground against which it is formed may be treacherous, and give way.

Such failures have occasionally happened, one of the most disastrous of them being the bursting of the dam of Dale Dyke Reservoir, above Sheffield, in the year 1864. By this accident above 100,000,000 cubic feet of water were suddenly let loose, rushing with tremendous violence down a narrow valley and through the town of Sheffield, and causing the loss of two hundred and fifty lives, with the destruction of property to the amount of hundreds of thousands of pounds. No wonder that the inhabitants of valleys in which water supply reservoirs are situate should feel anxious about their construction, and about the competence and skill of their builders.

Then the reservoir must not only be safe but it must be sound, *i. e.*, perfectly water-tight. Leaks must be prevented, not only in the artificial dam, but also in the whole interior surface of the reservoir, the strata in these mountainous countries being often fissured and treacherous.

It is impossible for me to offer any explanation of how an engineer is to produce a good, safe and sound reservoir, seeing that in the first place it is not the purpose of these lectures to enter into engineering details; and secondly that the difficulties to be encountered are so varied in their nature, and depend so much on local circumstances, as not to admit of any such notice as would be practicable here.

Supplies from Lakes.—Some large towns are supplied from natural lakes. This mode of supply is in reality the same as that just described. The lake is fed by streams from a gathering ground, and it is in fact only a reservoir, made by nature instead of by art. Or to put the comparison in another way, a reservoir is only a lake made by art instead of by nature. When, however, a lake is used for water supply, something must be done to it artificially to fit it for its work.

The popular notion that, given a lake, you may draw water without limit from it, as you might out of the sea, is a delusion. The essence of a reservoir is that it is a store of varying content: it can be filled when the supply comes to it, and when there is no supply it can be drawn down. Now a natural lake has usually a level pretty nearly uniform. To fit it for water supply this must be altered; it must be capable of being drawn down for the use of the district in times when there is no rain. This being done, we may consider the two cases identical.

Yield of Gathering Grounds.—The quantity of water which may be obtained from gathering grounds is a very complicated and difficult study. At the same time it is exceedingly important, for on the accuracy of its determination must depend the sufficiency of the supply to the inhabitants of a town. Cases have unfortunately not been uncommon where towns supplied from gathering grounds have been in great distress for water. In the long drought of 1868, Manchester, Bradford, Halifax, Sheffield, Preston, and many other towns, suffered severely, and the same thing occurred again last year, almost amounting in some places to a water famine.

The causes lie in the uncertainties of the meteorological conditions in our preeminently uncertain English climate, and they necessitate a most careful study of the problem by the engineers and promoters of water undertakings.

We can ascertain the area of the gathering ground with the greatest ac-

curacy. But the difficulties arise in estimating the quantity of *rainfall* we can get off it. For a long time the information gathered about this most important element of engineering calculation was very scanty. But of late years, thanks to the indefatigable labors of Mr. Symons, there have been collected, in his annual Reports on British Rainfall, a series of data of the most useful and valuable character.

The rainfall varies exceedingly at different times and in different places.

As to the variability at different times, I shall have hereafter to speak more fully.

To illustrate the variation in different places I may refer to an admirable map of the rainfall in the British Islands, prepared by Mr. Symons, which is published in the Sixth Report of the Rivers Pollution Commission, 1874. This shows that the annual rainfall in different parts of the country varies from 25 to 75 inches. But the extreme variations run much higher. For, taking single stations in 1883, the rainfall at the Stye, in Cumberland, was 190 inches, at Clacton-on-Sea, in Essex, it was only 18.7 inches—one ten times greater than the other.

These places lie wide asunder, but even in the same locality the rainfall will vary materially in sites only a short distance apart. And hence it is always desirable that, before any important proceedings are taken, the rainfall upon a tract of ground proposed to be used as a catchment area should be ascertained, as far as possible, by direct observations upon the ground itself.

Suppose, then, we have taken such observations, say, for a year, and suppose, for example, we find that the total annual rainfall over the area of our gathering ground amounts to 44 inches. Our first difficulty is that we cannot gather, for storage and use, anything like the total quantity of rain that falls. There is always a loss, which occurs in several ways.

In the first place, a part of the water will be returned to the heavens by evaporation; then another portion will be absorbed by the vegetation growing on the land; and, thirdly, another portion will percolate through pores and fissures of the earth, to enter subterraneous strata, and find its way out at a distance in springs.

Now, these three sources of loss vary exceedingly under different circumstances and at different times. They are naturally greatest in hot and dry weather. A shower occurring at such times will often contribute nothing at all to the reservoir, whereas, when the atmosphere is cold and damp, and the ground already wet, nearly the whole may become available.

The loss by percolation will vary materially according to the nature of the geological formation of the district. In chalk districts, for example, the whole rainfall is often absorbed into the earth, there being no surface streams whatever; whereas, on compact rock formations, the percolation may be almost nothing.

And then, much depends upon the inclination of the surface. If the ground is very flat the water will run off slowly, and will have more time to evaporate. In steep ground it will rush down rapidly into its receptacle.

In the face of these irregularities it would be impossible to give any accurate rules. All that can be done is to form some general notion of the results of experience.

Dr. Dalton, an eminent meteorologist, estimated that, taking the whole of England, only about one-third of the rainfall found its way into the sea, and this is estimated to be about correct as regards the Thames. But in mountainous districts the proportion of the rainfall flowing down the streams is greater, being often one-half or two-thirds, and sometimes even more.

It is usually considered more correct not to assume the losses as proportionate to the rainfall, but to estimate them at a fixed quantity, whatever the rainfall may be.

This quantity will vary from about 12 to 18 inches per annum, according to the nature of the ground. Steep ground of compact rock will give the minimum, flat ground of more permeable rock the maximum deduction, as in the basin of the Thames, where the rainfall is about 27½ inches. and the loss is about 18 inches.

Hence, out of our 44 inches assumed rainfall we must make this deduction before we can estimate the quantity of water available. For the sake of example, call this deduction 14 inches. This will leave 13 inches in the year

available for use. Having got this, it is only a matter of simple arithmetic to calculate, knowing the area of the catchment ground, how much water we can get in that year.

There is a very simple rule for this:

If R=rainfall in a given year in inches;
E=estimated loss by evaporation, etc., in inches;
A=area of gathering ground in acres;
then Cubic feet of water per annum = 3,630 A (R−E),
or, Gallons of water per diem = 63.15 A (R−E).

But now we come to another complication, which leads us to consider the use of the reservoir.

During the year that we have taken the rain will fall irregularly, some months will be wetter and some will be drier. But the supply must be uniform, or nearly so, and hence the reservoir must be of such size as to equalize the quantity, storing sufficient water in the wet months to tide over the drier ones. To illustrate this I may take an example out of Mr. Symon's tables:

RAINFALL AT BRECKNOCK, IN SOUTH WALES, FOR EVERY MONTH IN THE YEAR 1883.

	Inches.
January	7.06
February	10.19
March	1.67
April	1.20
May	2.22
June	5.14
July	3 73
August	1.25
September	6.04
October	5.81
November	5.55
December	1.88
Total for the year	51.74
Mean monthly fall	4.31

I have calculated what size of reservoir would be required to equalize these irregularities. so as to yield day by day a quantity of water equal to the average of the year, and I find for this purpose no less than about one hundred days' storage room would be required.

But there is another and a greater complication. In our simple hypothetical example we have assumed that we get, by our rain-gauges, the amount of rain falling in a single year. But this in only very imperfect information, seeing that the rainfall varies materially in different years. In some districts the variation is enormous. At Windermere, where the average of twenty-two years gave 79.85 inches, it sometimes reached 116.26 inches, and sometimes went down to 47.24 inches. But the worst feature of the variation is that there will sometimes occur several consecutive dry years.

Mr. Symons, in his report for 1882, has given a valuable table illustrating this. He has collected, with vast labor, the records of rainfall at forty-five stations, during 43 years. I may give the following as an example:

ANNUAL RAINFALL AT UCKFIELD, IN SUSSEX, FOR FORTY-THREE YEARS.

	Inches.		
1840	22.30		
41	36.30		
42	24.60	6 years average 24 in.	
43	30.09		
44	23.37		
45	23.03		4 years average 22 in.
46	25.11		
47	17.58	Minimum.	
48	38.03		
49	29.33		
1850	28.62		
51	24.26		
52	50.55	Maximum.	
53	31.70		
54	23.15		
55	23.80		
56	33.59		
57	31.74		
58	19.36		
59	33.48		
1860	42.46		
61	28.35		
62	30.01		
63	25.74		
64	23.48		
65	38.97		
66	33.79		
67	30.48		
68	30.51		
69	28.57		
1870	24.99		
71	25.64		
72	38.64		
73	30.06		
74	24.65		
75	29.02		
76	33.37		
77	39.58		
78	31.25		
79	33.00		
1880	31.79		
81	33.05		
82	35.90		
Mean of the 43 years.	30.08		

It will be seen that while the average of the forty-three years is a little over 30 inches, the annual fall sometimes reaches above 50 inches, and sometimes is as low as 17½ inches. Moreover, there were six years together when the average annual fall was only 24 inches, and four years together when it was only 22 inches.

It will be easily inferred from this, that a single year's datum of rainfall, which we have assumed in our previous example, will be of no use. It may have been a wet year or a dry year, or anything between. We must have, for our gathering-ground, data of the rainfall over a large number of years, embracing, if possible, all the variations of wet and dry.

How, then, are we to treat these data when we get them? We can, of course, deduce from them an average rainfall for the whole series But this, also, is no proper guide, unless upon the condition that we can store over all the excesses of the wet years, to supply the deficiencies of the dry years.

Now, I have taken some trouble to get a rough notion what size of reservoir we ought to have to equalize the forty-three years' rainfall shown in the above table, and I find it would require a store of something like 900 days' supply. It is altogether unreasonable and impossible that a water-works undertaking could be burdened with such a monstrous construction.

Mr. Hawksley has often urged this with great force. He points out that, however large, in reason, the reservoirs may be made, in wet seasons they will be full; and, as floods come down chiefly in wet seasons, they will then simply run to waste down the bye-wash—they cannot be stored; and as these floods help materially to swell the average, this average cannot be obtained from the reservoirs.

Mr. Hawksley gives, as the result of his long study of the question, and great experience, that it is impossible, practically, to spread the equalization over a longer period than three years. And, for the sake of safety, the three years taken for calculation must be the three driest years that come together.

Mr. Symons has deduced from his large table some general results which appear to prevail, and they agree fairly well with data laid down by Mr. Hawksley in 1868, before the Duke of Richmond's Commission.

It is found that the wettest year will have a rainfall nearly half as much again as the mean.

The driest year will have one-third less than the mean.

The driest three consecutive years will each have one-fifth less than the mean.

Or, more exactly, if R_m = mean annual rainfall over a long series of years, then

Rainfall in the wettest year
$= 1.4$ to $1.5 \times R_m$.

Rainfall in the driest year
$= 0.63$ to $0.67 \times R_m$.

Mean of the driest three consecutive years
$= 0.77$ to $0.79 \times R_m$.

Thus, if Q = daily quantity in gallons, for all purposes, required to be supplied from the reservoir, then

$$Q = 62.15A\left(\frac{4}{5}R_m - E\right),$$

which gives the relation between the area of gathering-ground and the quantity it will supply.

But it is further desirable to know the size of reservoir which will be required to equalize the rainfall over the three years selected. For this it is impossible to give any precise rule, it being so entirely a question of experience. But Mr. Symons has again furnished a statement which will be some guide.

The necessary storage will vary in different districts, for this reason, that in wet districts, the extremes, both of wetness and dryness, are less pronounced than in drier districts. Hence, in a rainy country, a smaller reservoir will suffice than in a dry one.

The general judgment of experienced practitioners appears to be that, for large rainfalls, a storage of 150 days' supply, or even less, will suffice; but in drier districts it may be necessary to go as high as 200 days. And this is a provision which may reasonably be borne.

Compensation.—But there is another point that the engineer has to consider in laying out water supplies from a gathering ground.

The essence of the arrangement is, that he takes possesion of a stream; intercepts it from its former course, and turns its water away in a different direction for the supply of a town. But there will be persons residing, or having property on that stream, who will have something to say about this arrangement; and engineers accustomed to such things know pretty well that riparian proprietors in this position have the habit of making themselves pretty loudly heard. They demand what is called water-compensation; and a few words will explain what this means.

Before the reservoir is made, the stream in question will vary exceedingly in its volume at different periods. In dry weather there will be very little water in it; while in heavy rains it will be a torrent swollen to a flood. This variable state of things is very inconvenient for everybody on the stream.

Now when a reservoir is put in, it gives the opportunity of remedying, in a large measure, these evils; for it will act as an equalizer for the stream, just as it acts as an equalizer for the town supply. When the floods come down they are absorbed in the reservoir, and in return for this, the reservoir, in addition to the supply furnished to the town, may be made to give out, also, an equalized supply to the stream in dry seasons. This is called compensation-water.

The quantity of compensation-water to be given may vary according to special circumstances; but in the manufacturing districts, it is usual to allow one-third of the total supply impounded; leaving the other two-thirds for the supply of the town. The quantity Q in the formula must, of course, comprehend both supplies.

It is usual to insert in Acts of Parliament stringent conditions to compel this supply of the compensation-water, and explicit provisions for determining its quantity. The most usual mode of gauging is by the flow over a weir, or through a measured orifice under a given head. But, as these depend on calculation, the riparian owners have, in some cases, demanded a more positive determination; and Mr. Bateman has contrived an ingenious machine for this purpose, which actually measures the water, as a publican would measure a pint of beer. It will be found described in Mr. Bateman's magnificent work on the Manchester Water Supply, p. 178 and illustrative figure.

A gauge-basin is prepared of exact known dimensions, into which the compensation-stream can be turned at any time; and the machine consists of a tumbling apparatus by means of which the stream can be turned into the gauge-basin instantaneously, and can also be diverted from it with equal celerity. By this means the duration of the flow into the basin can be exactly known, and the quantity flowing in a given time can be exactly determined.

Quality of Water from Gathering Grounds.—It is only necessary to say a word or two on this point.

If the grounds lie high, in hilly country, as they mostly do, the water is usually very pure and soft, not having much opportunity of acquiring contamination. If the lands are flatter and lower, the water flowing over them will have more chance of taking up foreign matters, and in these cases filtration is sometimes necessary.

There is, however, one kind of effect to which water, even from the highest land, is liable, namely, to discoloration by peat. Most of these high lands contain, in certain spots, masses of decaying vegetation, in the shape of morasses or peat-bogs. These collect the rain-water like sponges, and when it flows away from them it carries with it small particles of the vegetable matter, which render it brown in color. This is no great detriment to the use of the water; the presence of these brown particles does not render it at all unwholesome; but still it is objectionable to look at.

It is said, and I believe with truth, that this water will bleach if allowed a long run in an open conduit exposed to the light and the air.

And I may here notice an ingenious arrangement contrived by Mr. Bateman for diminishing the collection of brown water in districts where much peat exists. It is well known that the color is worse in the time of floods, when the greater flow of water through the peat bogs washes the vegetable particles out of them. Mr. Bateman has cleverly taken advantage of this fact to effect his object, by a "separating weir," as shown in his beforementioned work on the Manchester

Waterworks (p. 128 and illustrative figure). It consists simply of forming across the stream channel a narrow slit, which communicates below with the clear-water reservoir, or a passage leading to it. When the stream is clear it moves slowly and falls through this slit; but when it is in flood, moving with a higher velocity, it is carried over the slit without falling into it, and flows away by the natural course of the river.

Examples.—Towns supplied from gathering grounds are very common in hilly districts. I need not give any list, or any elaborate descriptions, but I will just name three of the most celebrated cases.

One is the supply of Glasgow from Loch Katrine, which was carried out by Mr. Bateman, in 1859. The loch, lying 367 feet above the sea, forms a large reservoir for the catchment-basin above it, in which the rainfall is very large—70 to 90 inches per annum. To fit the lake for supply purposes, its level was raised 4 feet, and arrangements were made so that it could be drawn down 7 feet in all. thus giving an available storage of 5,600 millions of gallons.

The conduit from the lake to Glasgow is 26 miles in length, of which, 13 miles are in tunnel under hills, and 4 miles are in iron pipes across valleys. It will deliver about 50 million gallons per diem.

The cost of the works was about £1,000,000 sterling.

The two other large supplies I will mention have rather a curious history. About the year 1869, there was a good deal of discussion as to the water supply of London. An impression was prevalent that the Thames ought to be abandoned; and two projects were proposed for supplying the metropolis from distant sources. One was by Mr. Bateman, from the head-waters of the Severn, in North Wales; the other by Mr. Hassard from the lake district of Cumberland.

In both these places the rainfall was large, and the water of unimpeachable quality, and the designs were both excellent and perfectly practicable. They were referred to the Duke of Richmond's Commission, who, however, came to the conclusion that, for the present at least, the metropolis did not require them; and they ventured a prediction that the fine sources of supply in these districts would probably be found more useful for the large towns nearer to them in the north-west of England.

This has actually occurred. Manchester has taken possession of the Cumberland, and Liverpool, of the Welsh supply.

The supply of Manchester and its outlying dependencies, from Longdendale, laid out by Mr. Bateman, in 1847, has proved insufficient for the growing demand, and in 1879 an Act was obtained for taking water from Thirlmere Lake, close to Hellvellyn.

The lake is but a small one, and to fit it for storage, its level will be raised 50 feet, which will give an available capacity of 1,300 millions of gallons. The rainfall is high—some 75 inches per annum—which at present is all wasted in useless and mischievous floods, and it is estimated that a supply of 50 million gallons per day may be obtained.

The natural outlet of the lake is to the north; but, by boring under Kirkstone Pass, a discharge will be effected at the south end, and this will be brought to Manchester by a conduit a hundred miles long. It will also supply, if necessary, towns along the line.

The lake is 533 feet above the sea, and the height gives ample fall.

The estimated cost of the work is £3,500,000.

Liverpool has been supplied for many years, partly by old wells in the sandstone, but chiefly from gathering grounds at Rivington, laid out by Mr. Hawksley many years ago. But here also the demand outgrew the supply, and larger sources had to be resorted to. The gathering grounds of North Wales were fixed on, and the works of supply are now in progress.

The River Vyrnwy, one of the head-waters of the Severn, is embanked in a favorable spot, forming a great artificial lake of 1,100 acres area.

The height is about 825 feet above the sea, and the water will flow to Liverpool by a conduit 67 miles long, including 4 miles of tunnel.

The quantity to be obtained is estimated at 40 million gallons per diem.

Rivers.

The third mode of making rainfall available is by drawing it from a river of some magnitude, flowing through low ground. It is a very common thing to find large towns situated on or near

large rivers. Probably one of the motives for establishing them there may have been to furnish them with a convenient water supply; but at any rate, when a river of fresh water flows close to a town, it offers, *prima facie*, the most obvious source for this purpose, and many towns are so supplied.

We may say something as to river supplies, both as to quantity and quality.

In the first place, as to quantity. The capability of rivers in this respect was investigated at some length by the Royal Commission of 1869, having reference specially to the Thames. They pointed out that the river was fed, not so much by the drainage of rain from the surface, as by the delivery of water through springs from the large stores laid up in permeable strata; and that this fact gave a permanence of flow, which was of great importance in water supply. As a proof of this, it was remarked that during long droughts, when many towns depending on catchment-supplies were in great distress for water, the Thames and the Lee seemed not to have been diminished below the ordinary flow of dry years, a result entirely due to the equalizing effect of the great subterranean stores contributing to them. The Royal Commission reported "That the abundance, permanence, and regularity of supply, so important to a large town, are secured much more efficiently by the great extent and varied geological character of a large hydrographical basin, than by the very much more limited collecting areas available on the catchment system." And this remark will apply to river supplies generally.

In regard to quality, however, there is much more to be said, as it is on this ground that objections are usually raised to river supplies. We may exclude from consideration those rivers which are specially fouled by manufacturing operations, as in Lancashire and Yorkshire, confining our attention to rivers which flow chiefly through open country and agricultural lands.

Referring back to my remarks on quality generally, I mentioned three classes of impurities; and these have all to be considered in regard to rivers.

First, there is the class of impurities held in mechanical suspension. All rivers of any magnitude are liable to be more or less turbid, by the surface drainage of lands; but, as I have explained, such impurity can always be removed by efficient subsidence and filtration.

Secondly, as to mineral matters in solution. A river will almost always contain lime, from its being largely fed by springs; but this is so modified by the surface drainage, that the hardness is usually very moderate; and in this particular, therefore, no great objection generally arises.

It is the third class of impurity, namely, organic contamination, which is of the most importance. And I have purposely postponed the consideration of this till now, because it is in river supplies that this kind of contamination is most to be feared.

I repeat that this, like all other points regarding quality, is a matter specially for chemists, and that the best professional advice must always be called in before a final judgment is arrived at as to the propriety of using a river supply. But I also repeat that a water-engineer is bound to have a certain general knowledge of the subject; and taking well-ascertained data as his guide, he is expected to form, by careful observation and common-sense reasoning, at least some preliminary judgment on the case before him. All, therefore, I profess to do, is to specify a few points that may reasonably occupy the engineer's attention in regard to the organic contamination of river water.

In the first place, we must not be frightened at the name. There is often a horror of the very idea of "organic contamination" in drinking water. But this, taken generally, is a mere foolish prejudice. We must recollect that all our solid food is organic, and almost all our drink, except water, depends on organic matters for its pleasantness and its usefulness. Hence the mere fact of water containing organic matter means nothing against it. We must discriminate what kind of matter it is, and where it comes from.

Water washing over land surfaces, covered with vegetation, must necessarily collect organic particles. But these will for the most part be harmless, and when filtered the water will be perfectly wholesome. Even decaying vegetable matter, though it may be offensive, is seldom

noxious. There is a very common example of this in peaty water, which really comes from decaying vegetation, but which no one objects to, except for its color.

The contamination to be guarded against is that of animal origin. River water is liable to be polluted with the excreta of animals, sometimes in the worst form of concentrated town sewage. No doubt this kind of contamination is both disgusting and dangerous; and it would offer a most powerful objection to the use of rivers as sources of water supply, were it not for a great principle of nature that tends strongly to counteract its evils.

This principle has been fully explained by the chemists. The noxious substances forming animal excreta are, generally speaking, exceeding instable in their chemical composition; and in the presence of oxygen they are constantly tending to change, this change involving a destruction of their noxious properties, and their conversion into inert, harmless compounds. This change or oxydation will, we are told, be certainly brought about by exposure to the air, or to the action of water, which almost always contains free oxygen enough to produce the effect required.

Nobody, I believe, disputes the existence of this purifying influence; indeed, if it did not work daily, the civilized world could not go on. The only points of disagreement are as to the extent of its action, and the time necessary to effect it in certain cases.

Now, keeping this principle in view, let us consider what are the circumstances that give rise to the organic contamination of rivers.

It is not uncommon to hear it said that a river must be necessarily contaminated with the excreta of the whole of the inhabitants living on its area of drainage. But such a statement is a gross exaggeration, and ignores the purification principle altogether. What is the position of the inhabitants on the drainage area? The fact is that a very large proportion of them live in what may be called the country, *i. e.*, widely and sparsely dispersed over the land, and not collected in towns. In the basin of the Thames, for example, above the tideway, less than one-fourth live in towns of two thousand inhabitants and upwards, three-fourths being spread over the wide surface of the country.

Now, everybody who has seen life in these country districts must know that the excreta both of the human and of the lower animals are, as a matter of ordinary economy, disposed of directly upon the land, and it is notorious that such a disposal is the most favorable for their complete oxydation, and for the speedy destruction of their noxious properties.

It is generally admitted that by the application of animal excreta to land, in the manner known as "sewage irrigation," if laid out and managed to the best advantage, the noxious elements will become oxydized and destroyed. It follows, therefore, that, so far as regards all these country-produced excreta, the whole drainage area forms one immense sewage-farm, on a scale of efficiency sufficient to purify hundreds of times the quantity thus put upon it. Hence, so far as this element of pollution is concerned, no great fear need be entertained as to any dangerous contamination of the river water.

Again, we often hear about the pollution by the washings from manured lands; and even the sheep, cattle and birds are accused of poisoning the river water. But here again the same principle applies; the excretal matters being exposed to oxydation and destruction in the most favorable way.

That this reasoning is true is proved by the most ordinary common-sense considerations. These causes of organic contamination have been at work for ages; ever since the lands have been inhabited and cultivated. And during the whole of this time the rivers have been used as sources of water supply to the whole country, and nobody has been poisoned; in fact we may say, in regard to the bugbear of universal organic pollution, in the words of one of our most entertaining poets—

> "In spite of all this terrible curse,
> No one has seemed a penny the worse!"

We must not, however, forget that we have the other fraction of the population to consider, namely, those who are collected in towns lying on the river or its tributaries above our proposed source of supply. For if these towns are system-

atically drained, and discharge their sewage into the stream, there is undoubtedly introduced thereby an element of contamination of a really serious character.

This cause of pollution is, it must be observed, of comparatively recent introduction. It has brought in elements of offensiveness, and indeed of danger, which have not existed before. While the river was left to natural pollution only, it worked its own natural purification. But now that we take pains artificially and purposely to damage its quality, it is by no means certain that the same result will follow.

But even in this worst of all contaminations, the case is not hopeless. In 1876 an Act was passed to prevent the pollution of rivers; and it is provided that no sewage shall be allowed to flow into any stream until the authorities of the place have used the best practicable and available means of rendering it harmless.

This opens the very large question of sewage treatment, which I cannot pretend to discuss here. I will only allude to the two modes now generally practiced. The best is what I have already mentioned, namely, application to land—by sewage irrigation or filtration. If this process is fully, efficiently, and carefully carried out, all authorities agree that the noxious qualities are practically destroyed, and the water is restored to a state closely approaching its original harmlessness. The other process is by chemical precipitation. By this the worst parts, the suspended solids, are removed, and so a great deal of good is done; but the effluent will still be impure.

However, we must not leave out of sight the great saving element of the purifying power of the stream. For if, after either of these processes, sewage contamination is still introduced, yet provided a sufficiently long run, and a sufficient time, are given, nature will probably do what is necessary to complete the purification.

Several processes will assist in this work. In the first place, a portion of the organic matter will be removed by fish and other animal life. A further portion will be absorbed by the growth of aquatic vegetation. Then we have, finally, the decomposing power of the fresh water in the river, which always contains much free oxygen, eager to attack the instable organic compounds the moment they enter. And this action is very much facilitated by the motion of the stream, particularly if it falls over weirs.

Chemists differ as the extent and as to the speed of this purifying action, but, as a matter of practical observation, its beneficial effect is most positive and unquestionable. In many cases where a mass of sewage has been bodily discharged, in its most crude state, into a running stream, no trace whatever has been found of any deleterious matter, either by chemical tests or by practical use of the water, a few miles lower down.

I say this, however, with a reservation as to what is called the "germ" theory. Some authorities have expressed the opinion that if the germs of certain zymotic diseases once enter town sewage, they cannot, by any practicable treatment, be destroyed or removed, and that water receiving such sewage should always be considered as dangerous, and improper to be used for drinking. On the other hand, there are many authorities who think this theory merely fanciful, and unsupported by evidence. It is beyond my province to discuss the point. I only mention it, and it must have the consideration it deserves.

On the whole, however, I believe it to be a sound conclusion that, although every care and caution should be used in adopting river supplies (which are often so very convenient), they ought not, by unreasoning prejudice, to be tabooed as ineligible. It is the business of the engineer to make the great powers of nature subservient to our use and convenience; and the purifying power of nature is certainly one that he should take advantage of if he can.

It is worthy of remark that in some cases the water of a river may be taken, not out of the river itself, but out of the thoroughly saturated bed in which it runs. It often happens that the ground through which the river forms its course is gravel, or some open porous alluvial stratum. This is of necessity charged with water, and a plentiful supply may be drawn from it, which has undergone a natural filtration. The supply of Oxford is obtained chiefly in this way, and the same thing has been lately done to a con-

siderable extent by some of the London water companies, who find a fine, clear, and ample supply in the gravel beds near the Thames at Hampton. The water in these cases does not necessarily come from the river; it may often consist of springs and subterranean drainage waters, which are flowing towards the river, and are intercepted on their way.

Supposing a river to be chosen as the source of a town supply, the operations of taking it are so simple as not to require any detailed description. The water is first allowed to deposit its grosser particles by subsidence in large tanks, after which it is filtered, in the manner I have already described, and is then pumped up to the town.

Wells.

The modes of utilizing the rainfall which we have hitherto considered, have all been founded on the supposition that we take the water on the surface of the ground. But some portion of the rain will percolate through pores and fissures of the earth, and will store itself subterraneously in permeable, or, as they are termed, water-bearing strata. In some districts where these strata form the surface beds, the rain disappears with marvelous rapidity, and in these districts, consequently, there are few or no surface streams. On the chalk downs, for example, there are no rivulets in the valleys; the water that would feed them has all gone below.

The water is stored in these strata in two ways: First, in the pores of the rock itself; and when the material is of an open grain, the quantity of water held in it is much more than one would suppose. But this storage is largely augmented by cracks, fissures, and hollows. These are very important, for they serve not only as reservoirs, but as drains to the substance of the rock generally. And it is by tapping these fissures that the most plentiful supplies are obtained.

The most common mode of making use of subterranean waters is by the old plan of sinking wells.

There is a marked distinction to be drawn between shallow wells formed in superficial ground, and deep wells sunk into the lower subterranean strata. Shallow wells are exceedingly common and exceedingly useful. The alluvial beds lying so largely on the surface of the earth receive water very readily, and wells sunk therein form the chief sources of supply in country places generally.

Now, although the water of surface wells is often not very good, yet, if the strata are not liable to be specially contaminated with noxious refuse, it may be safely used. But this condition is not always present. Even in an isolated farmhouse or country residence, there must be a cesspool or similar receptacle, and there is danger, unless great precautions are taken, of liquid from this penetrating the strata and getting to the well.

In towns, this kind of contamination is much more probable, and surface wells become, consequently, especially dangerous, so much so as to be generally prohibited for drinking purposes by health authorities. The alarming outbreak of cholera in Soho, some years ago, due to a contaminated surface well in Dean Street, will long be remembered.

But deep wells, drawing their supplies from strata lying low in the earth, are in a different category, and form excellent sources of water supply.

In some cases a deep borehole will tap a water-bearing stratum covered by impervious beds, and the water, being fed from higher levels, will rise up the borehole, sometimes above the surface of the earth. This is the phenomenon called an Artesian well, with which all will be familiar. But wells of this kind are exceptional. The ordinary well is a large shaft sunk into a water-bearing stratum, where the water lies at a low level, and has to be pumped up to the surface.

The two most important water-bearing strata in England are the chalk and the new red sandstone, and many towns are supplied from them.

We may consider a little what takes place in regard to the water in subterranean strata. It is not stationary, it tends to move away toward low points, where it can find an exit in springs, or into low-lying rivers, or into the sea. And, as a consequence of this motion, it is found that the line of water level within the strata is always slightly inclined toward the points of discharge,

the angle of inclination representing the head necessary to force the water through the interstices of the rock. In the *Proceedings* of this Institution, vol. ix., p. 154, will be found an instructive section of the chalk strata near London, showing the water-line, inclined, as I have described, towards the Thames and the Colne. The inclination of the water-line varies, in this place, from about 13 to 26 feet per mile, according to the closer or looser texture of the material, but in many other places it is more rapid, sometimes reaching 40 or 50 feet per mile. The levels of the water in these cases are known by careful observations in wells sunk into the strata at various points.

It is instructive to note the effect that will be produced when we begin to pump out of a well. Before the pumping begins, the water will stand at its normal level; but when the pumps are set to work the surface of the water in the well will immediately descend. The reason of this is, that to supply the well, the water must flow into it from the neighboring parts of the strata, and to enable it to do this, its surface must have an inclination to give it the necessary head to overcome the friction through the interstices. This produces a conical depression all around, the depth and extent of which will adjust itself according to the quantity of water pumped, so that, when this adjusted level is attained, the pumping may go on at the same rate without further depressing the water level. But, if the rate of pumping is increased, the water will be further depressed, till it finds its proper level as before, at which it will remain. There will thus be found a stationary level of water in the well corresponding to every given rate of pumping, so long as this does not exceed the possible yield.

At the same time as the water-level in the well becomes more and more lowered, the area of the cone of depression extends farther and farther around, until it may reach a considerable distance; and this is the reason why a certain rate of pumping from one well may lower the level of water in another well in the neighborhood; which simply means that the cone of depression belonging to the first well has extended so far as to reach the second well. Cases of this kind are very common, and sometimes give rise to a good deal of trouble.

In order to increase the facility of getting the water out of the strata, it is customary to drive tunnels from the well in various directions, so as to enlarge the area of collection. A good example of this is found in the Brighton Waterworks, of which an account has been given by Mr. Edward Easton, in the *Transactions* of the Brighton Health Congress, 1881, p. 48.

Brighton is surrounded on three sides by chalk strata, which absorb a very large quantity of water. The level of the water can be easily traced by wells, and it is found to rise gradually from the sea at the rate of about 40 feet per mile; this slope representing the friction of the current flowing down gradually into the sea, as it is replenished by fresh stores, either from the rain above, or the chalk strata behind. Two wells were sunk to the depth necessary to reach the water level, but these alone did not furnish sufficient water, and tunnels or adits were driven to increase it. It was found that the chalk was largely fissured, the fissures mostly extending longitudinally from north to south, indicative, probably, of the erosion of the rock by the subterranean flow of water in that direction. Advantage was then taken of this fact by driving the tunnels from east to west, so tapping the fissures successively at right-angles, and the result was a very copious supply. The quantity pumped is about 3¼ millions of gallons per diem.

In regard to the quantity of water which may be got out of a well no rule can be given. Some people have fancied that (as I have said in regard to lakes) these subterranean reservoirs contain an unlimited store, and may be pumped off *ad libitum*. I need hardly say here that this is a delusion; the only source of supply is rain, which gets into these strata from their exposed surfaces, and the yield of a well must always depend, first, on the amount of rain which the strata can collect, and, secondly, on what portion of this can be enticed into the borehole. Neither of these can be determined beforehand, and, therefore, the quantity to be got must be a matter of experience.

The water obtained from wells is usu-

ally bright and clear, and free from organic matter. This is the result of the natural filtration it has undergone. But it is generally rather hard, and is well adapted to treatment by the softening processes I have described in a former part of my lecture.

Springs.

Finally, as a mode of obtaining water, we may make use of springs.

The nature of a spring is familiar enough to those who have studied geology. It is simply a place where the water stored in a subterranean stratum finds access to the surface of the ground at such a low level that the head of water lying above it keeps up the discharge.

There isnot much to say about supplies obtained in this way. The springs are simply collected and conveyed to reservoirs for distribution. One of the most magnificent examples is the New River, a conduit 40 miles long, constructed by Hugh Myddleton, in 1613, to bring into London the clear waters of springs at Chadwell and Amwell in Hertfordshire.

Lancaster is supplied by springs in the high moorlands of Wyresdale, 8 or 10 miles from the town, the waters being intercepted by small pipes, and brought down by large mains. The works for this purpose were originally designed in 1852 by Sir Robert Rawlinson, and have since been extended by Mr. Mansergh.

Malvern is also a good example. A great many springs were found to be issuing from the sides of the well-known hills in the neighborhood, and have been utilized by Mr. Hawksley, so as to afford an ample supply of water of the purest kind.

In regard to the quantity obtainable from springs, engineers ought to be very cautious, for there is no means of determining *a priori* how their flow may vary, and in dry seasons they may fail altogether.

Internal Distribution.

Having now gone over the several modes of obtaining water for town supplies, I pass on to a branch of the subject which applies to all these modes alike, namely, the distribution of the water within the town.

The first step in this usually is to bring the water to reservoirs constructed near the town, at such elevations as shall allow it to flow by its own gravity throughout the district. These reservoirs are called "service" reservoirs.

If the water is obtained from a gathering ground, the source will usually lie at such an elevation that the water may flow down along a conduit from the catchment reservoir into the service reservoirs. But, if the supply is obtained from a low-lying river, or from wells, it must be forced up to the service reservoirs by pumping power. Such is the case in London, where steam-power to the amount of 17,200 H.-P. is in use.

I might here go into the subject of pumping-engines and pumping-machinery, but this is hardly necessary, as the subject has often been discussed before the Institution. I will only make two remarks of a very general character.

In the first place, in pumping through a long and large main, it is most desirable to keep the current uniform and regular, avoiding shocks or sudden changes of velocity, which are very trying to the metal, and often cause bursts. For this reason it appears to me that double-acting engines, regulated by a fly-wheel, are to be preferred to single-acting ones of the Cornish type. The Cornish engine had, many years ago, a justly-earned reputation for superior economy; but now that the use of steam is better understood, this no longer exists, and I cannot see any other motive for the retention of this form of engine.*

* The history of the application of the Cornish form of engine to water-works purposes is curious. Some half century ago the engineers of the center and north of England became aware of the reports published from time to time of the extraordinary economy of the pumping engines in the mines of Cornwall. These reports at first obtained no credence, and even when they were found to have some foundation, the most singular attempts were made to explain them away. In the midst of this controversy, Mr. Thomas Wicksteed, the Engineer to the East London Waterworks Company, determined to throw light on the question by buying an engine in Cornwall and setting it up to work on his own premises, where it could be thoroughly tested and examined. The result was fully to establish the truth of the great economy claimed, and so arose the idea of the superiority of the Cornish form of engine for pumping purposes.

When, however, the working of the engine came to be investigated, it was found that the economy was due chiefly to the large amount of expansion made use of, combined with some other modes of economizing heat; and there appeared no reason why, by proper measures, these might not be as efficiently carried out in other forms of engine. Accordingly, when the new Lambeth Water-works were designed, in 1848, Mr. James Simpson, the engineer, commissioned Mr. David Thomson and myself to endeavor

The same principle of regularity of motion also dictates a preference for a particular form of double-acting pump, called the "bucket-and-plunger" pump. It is simply a lifting bucket-pump, the rod of which, passing through a stuffing box at the top, is enlarged to one-half the area of the pump-barrel. The effect of this is that in the down stroke the rod acts as a plunger, and expels an equal quantity of water to that effectively lifted in the up stroke. I do not know who invented this ingenious contrivance, but it was made for the Lambeth Water-works pumping engines by Messrs. Simpson & Co., in 1848. Its advantage is, that although the pump is double-acting, the motion of the water through it is always in the same direction; whereas, in the ordinary double-acting pump it is reversed in the barrel at each stroke. Owing to this peculiarity of the bucket-and-plunger pump, it is possible that the motion of the water may continue, to some extent, at the dead points, and under certain circumstances I believe that the curious result has occurred of the pump delivering more than its calculated quantity.

There is another point in regard to pumping machinery worth mentioning, that is, the necessity of duplication. Everybody knows that, in spite of the utmost care in the manufacture, accidents will happen, and hence a duplicate provision of engine and pumps is an abso lute necessity where the supply of a town is at stake. Such a provision is also highly expedient and economical, in order to give proper intervals of rest for cleaning and repairs.

It sometimes happens that a town lies in such flat ground that no elevated site for service reservoirs can be found. In this case a tower may be built, and a reservoir placed on the summit, forming what the French call a "chateau d'eau." Such erections are, however, expensive, and in some cases the plan is adopted of pumping directly into the distributing mains, so giving the necessary pressure by steam power, and not by the gravitating head from a high-service reservoir.

This, however, is both a difficult and a disadvantageous plan. It is difficult because of the constantly varying consumption, which renders it troublesome to regulate the working of the engines, so as to adjust the quantity pumped to the draught on the mains. It is, moreover, disadvantageous to supply a town by direct pumping, because this plan is unfitted to give a large and free supply on a sudden emergency in case of fire. High reservoirs will do this naturally, being always ready, if kept properly filled, as careful water-works authorities will take care they always are, particularly in the night, when fires are most likely to occur. It is obvious, also, that they provide for fluctuation in the town consumption, while they allow the engines which supply them to work at uniform speed and uniform pressure, the most advantageous conditions in every way.

Sometimes, when there is a small high-service reservoir, the two plans are combined. The engines pump into the town at the same time as they pump into the reservoir, which then acts as a regulator, equalizing both pressure and quantity.

The size of the service reservoir must be sufficient to fit it for the double duty before named, *i.e.*, to regulate the fluctuation of the demand, and to hold a store for sudden emergencies. It is found that these objects will be attained if the reservoir holds from one to one and a-half day's supply.

Service reservoirs, if they are in or near the town (as they usually are), ought to be covered. This has several advantages. It preserves the water from contamination by soot and dirt falling from the air. It keeps the water cool in summer, and will go far to prevent it freezing in winter; and, by excluding the light, it is said to discourage the growth of vegetation, to which some waters are very liable. The London Water Acts require that all reservoirs of filtered water within five miles of St. Paul's, shall be covered.

When a town is very hilly, it is necessary to have several service reservoirs at different levels, in order to avoid too much pressure in the distributing mains at the lower parts of the town. For

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to design engines in which this should be done. The result was the construction of some large engines on the compound or double-cylinder principle, which fully realized the expectations entertained of them. Since that time the compound principle has been further developed, and the superiority of the Cornish form exists no longer.—See Wicksteed on the Cornish Engine; Pole on the Cornish Engine; and a paper in the Transactions of the Institution of Mechanical Engineers, July, 1862.

this purpose the town is divided into zones of different levels, each having its own service reservoir.

From the service reservoirs the water is made to flow by cast-iron pipes (or "mains," as they are termed), which ramify in all directions through the streets, the sizes being, of course, properly proportioned to the maximum quantities of water flowing through them. From these mains the water is carried by communication pipes (usually of lead) into the houses. I need not go into any description of this system of pipes, with all their various connections, valves, and appliances; they will be familiar enough to you.

Constant and Intermittent Supplies.—I must, however, say something of the two systems under which town supplies are given, namely, the intermittent and the constant-service systems.

The most natural and obvious way of supplying water is to keep all the supply pipes constantly charged under pressure, so that, whenever any customer wants water, he has only to open a cock or tap to get it. And, no doubt this must have been the mode attempted when house supplies were first given. But a difficulty would soon arise. The cocks and fittings in the houses, after being in use some time would begin to leak, and there would be a waste of water, which, if it became large, would overtax the powers of the water-works to supply. This evil was so serious, and so very difficult to remedy, that it led to the introduction of an ingenious device to evade it. The water-works people said to the consumer, "We cannot afford to give you a constant supply of water which you allow to run to waste. You shall put up a cistern in your house, capable of holding as much water as you can reasonably use in twenty-four hours. We will fill that cistern for you at a certain time every day, and leave it in your care, and then, if you choose to waste the water, it will be your loss and not ours." This was done in a great many towns. The town was divided off into districts, each supplied from the chief mains by a special service main, shut off by a valve. This valve was opened by a "turn-cock" for an hour or two every day, when all the house cisterns in that district were filled. Thus originated what is called the "intermittent" system of supply. It was a great convenience to the companies, as it not only saved them from the waste, but (if the town was supplied by pumping) it enabled them to regulate the action of their engines with much facility.

But then arose sanitary difficulties. It was found that the storage of water in these house cisterns, which were generally very badly looked after, rendered it liable to contamination, particularly on account of connections with water-closets and drains. Hence, when, some thirty or forty years ago, a great sanitary movement took place, the state of the water-supply of towns served on the intermittent plan was strongly condemned; and it was demanded by sanitarians that the house storage should be abolished, and the water served direct from the mains. It was proved that this could be done, and that the objection as to waste could be got over. I believe that our veteran Past-President, Mr. Hawksley, was the first, or one of the first, to show this. He laid out the supply of Nottingham in 1831, and it has never had any other than a constant supply—so constant that the water has never been shut off since, except for a few hours at a time. Many other towns were afterwards similarly supplied by him. Mr. Bateman also successfully introduced the system at an early period, and warmly advocated it. It being thus proved that the constant service was practicable, the Legislature, when they passed the Water-works Clauses Act in 1847, enacted that, as a general rule, "the supply should be constantly laid on at such a pressure as would make the water reach the top story of the highest houses."

Although, however, the difficulties have been surmounted, yet they have required a great deal of thought, attention and ingenuity to make the system a success. This is most especially shown when it is attempted to change a town or district from intermittent to constant supply. In such a case it would not do simply to turn on the water for the whole day. The waste would be so enormous that no ordinary water-works could meet it—it would simply be turning the water into the sewers. The promoters, therefore, have had to investigate, with the greatest care and perseverance, how this waste arises; to study every cause by

which water can run away unutilized, and to meet every such case by attention to the most minute detail. The work of doing this has been much more difficult than is usually supposed, and its successful accomplishment has been a great triumph of mechanical skill. I will endeavor to give, as briefly and generally as I can, some idea of the nature of the defects, and the manner in which they are remedied.

In the first place, the introducers of constant service have convinced themselves that the evil does not arise to any great extent from a willful or even a careless, waste of water by the consumers. If it did, constant supply would be impracticable. No doubt such waste does occur to some extent, but it may easily be kept down by stringent prohibitions and moderate inspection. It is found that, among all classes of the public, there prevails a sufficient sense of propriety to prevent serious waste, which is generally a nuisance and an inconvenience to the consumer.

The principal difficulty in this respect has been the mistaken zeal of sanitarians, who have told the poorer classes that it is a good thing to let water run to waste in order to clear out the drains. This is a gross blunder. It has been pointed out, over and over again, that these little dribblings can have no effect whatever in removing any obstructions or accumulations. The ordinary domestic use of water is sufficient, if properly managed, to keep house drains clear, and as to large sewers, it is the business of the municipal authorities to look after them. The waste of water in a house can do no good, and may do much harm.

The waste to be fought against is due, not to the action of consumers, but simply to defective arrangements in the pipes and fittings. It may arise either in the streets or in the houses, and occurs frequently in both. Let us first consider the house fittings.

In the first place, the pipes may be too weak. With constant service the pressure is high and continuous, and the pipes may give way. Hence, a scale of strengths of pipe must be prescribed.

Then the joints of the pipes are often badly made, and leak. This also must be provided against.

Then the draw-tap is of much importance. The ordinary plug-tap is a very bad thing; it has two defects: First, it shuts the water off too suddenly, causing a jerk and great strain; and, secondly, it soon gets leaky, and the constant dripping from a leaky tap will run away with an enormous quantity of water. The use of this kind of tap is forbidden, and a screw-down tap is always provided; it shuts the water off gently, and, if of proper construction, will keep in order a long time, and may be repaired with great ease.*

The ball-tap, which is necessary to some extent, even under constant service, is the source of much waste. There are two precautions against this—first, to get the article of thoroughly good construction; and, secondly, to ensure its being promptly attended to when out of order. This last object is provided for in a particular way. It is forbidden that any cistern shall have a waste-pipe by which the water can run away into the drains unseen. The only overflow must be by a pipe which discharges into some conspicuous place, where the discharge will attract attention and produce inconvenience. This is called a warning pipe, and its action will compel a householder to get the tap repaired without delay.

Then, one of the greatest causes of waste has been the supply to water-closets. The ordinary apparatus, if properly used, does not consume more than a fair quantity; but it is liable, in the first place to get out of order, and secondly, to be grossly abused, by propping up the handle, under the mistaken notion already alluded to, that this is good for the drains. The remedy is an ingenious contrivance called a waste-preventer. It exists in several forms, but the one most generally approved is the divided cistern apparatus, which, I believe, was first designed by Mr. Hawksley. The cistern is divided into two parts, which I may call A and B. A is fed from the main by a ball-cock in the ordinary way, and when the apparatus is at rest there is a com-

* The screw-down tap was invented by Mr. Edward Chrimes, of Rotherham, and was patented by him in March, 1845. Some years ago there was a long and hard-fought dispute before the magistrates of Edinburgh as to the construction of tap proper to be used in constant-service fittings, which resulted in the condemnation of the ordinary plug tap, and the establishment of the screw-down tap as the only suitable thing.

munication open between A and B, which fills B. When the handle of the apparatus is pulled, after using the water-closet, the water contained in B is let down into the pan, but at the same time the opening between A and B is closed, so that no more water can be used than B contains, and therefore no waste can be caused, either by accident or design. When the handle is let go, the communication between B and the pan is closed, and that between B and A opened, which charges B again for another use when required. When this is properly made it will keep in order a long time, and is very easily repaired, and it forms as efficient a flushing apparatus for the drains as can be devised.

This, or something equivalent to it, is the only apparatus that is allowable for a water-closet, under the constant-supply system. All simple cocks and valves are expressly forbidden, not only as allowing waste, but on sanitary grounds also. In the poorest class of houses, where the expense of the waste preventer would preclude its use, it is better, on every ground, to allow the water-closet pan to be flushed down by hand, than to "lay on the water," as it is termed, by an imperfect and wasteful cock or valve.

There are other precautions in regard to baths, hot-water boilers, and so on; but I need not trouble you with further details. I have said enough to give you a general idea of the nature of the precautions used.

These precautions are always embodied in a set of regulations, which are carefully prepared, and which the water authority of any town must have power to enforce strictly and stringently; otherwise the great boon of constant water-supply cannot be given.

But they must be supplemented by another power—that is, a control over the plumbers who do the fitting work; for, in spite of all provisions as to the construction of particular articles, if the work generally is badly done, it may give immense trouble. I am sorry to say that the character of the trade generally is not such as could be wished, and great trouble has been experience on this head, from the difficulty of obtaining any legal control. But the water authorities have generally adopted the plan of keeping lists of "authorized plumbers," who enter into an engagement to conform to the regulations, and to do their work in a proper and creditable manner; and the moral control thus given has been usually found effective.

Then, finally, the water authority must have a reasonable power of inspection, and of inflicting penalties for willful or careless waste. But, as I have said before, experience has not shown that this is, or need be, carried out in an oppressive or offensive way.

These measure have been found to suffice for checking the waste, so far as the house fittings are concerned. But there is another cause of waste more difficult to deal with, namely, from leakage in the mains and service pipes in the streets. The mains often get disarranged by the traffic, and leak at the joints, or the small pipes leading into houses decay or get damaged; and leaks from these sources will often go on for a long time undiscovered, the water finding its way into the drains. This cause of waste is often most troublesome in changing from the intermittent to the constant supply.

The difficulty is to find such leaks, and their discovery has been much facilitated by an operation that was introduced in Liverpool some years ago, and which has been fully described to this Institution by Mr. Deacon. It consists in isolating a certain district, and in ascertaining what quantity of water is used therein, at any given time, by applying, temporarily, a meter on its supply main. This will indicate whether more water is passing than ought to be consumed there, and then, by a detailed examination, the locality where the waste takes place can be soon identified. One means of doing this is ingenious, namely, by placing a "hydrophone," or sounding-bar, against any suspected pipe, when, by applying the ear to the other end of the bar, the passage of water through the pipe can be distinctly heard. This will not only detect street leakages, but may also give an idea whether waste to any serious extent is going on in the houses. The leak-detecting operation here described has been of great utility, and has done much to facilitate the introduction of constant supply.

The history of the London supply in regard to constant service, is curious and instructive.

Until within the last ten years the supply was entirely on the intermittent plan. The usual sanitary question had often been agitated; in many districts the supply was disgracefully bad; the propriety of introducing the constant service had been often suggested, and in the Water Act of 1852 a provision had been made to that effect. But notwithstanding the well-known fact that this system was successfully at work in other towns, the measure was always opposed by the companies, on the ground that the waste would be so enormous as to render the system impracticable. And, in the face of this opposition, nothing was done.

Still, however, the demand for the change was very urgent. It was strongly recommended by a House of Commons committee in 1867, and again by the Duke of Richmond's Royal Commission in 1869; and immediately after this last date the Government, earnestly desirous to carry out the measure, determined to institute inquiries as to its practicability.

They did me the honor to entrust me with the investigation, instructing me to visit several country towns where the system was said to be in effective operation, and to make myself thoroughly acquainted with the facts, and, in particular, with the modes of preventing the waste that was so much dreaded; and, having done this, I was to examine the state of things in London, and report if there were any real obstacles to the application of the system there.

The reports which I made on this matter were published as Parliamentary papers, and are well known to all parties interested in the question.

The general results were these: In the first place, I found that the system was in perfect and successful operation in many towns; that several towns had been and were being successfully changed from the intermittent to the constant system, and that, under this system, the consumption of water was much less than under the intermittent plan in London. I also described fully the causes of waste and the means adopted, with success, for checking it.

In the second place, I described the result of my examination of the circumstances of the London supply, and I endeavored to show that, if proper means were used (which I described in some detail), the constant service might be successfully brought into the metropolis. And I ventured to express the opinion that the change would be attended, in the end, rather with an economy than with a waste of water.

It was a great satisfaction to me to know that this report not only satisfied the Government, but also to a large extent satisfied the water companies. For when, in the following year, a bill was brought in for the purpose of effecting the change, the companies accepted it in a conciliatory spirit, and it became law on the 21st of August, 1871. Under the provisions of this Act, a long inquiry was held in 1872, by Commissioners appointed by the Board of Trade, for the purpose of settling the regulations to be adopted for efficiently carrying out the constant-service system; and, having paid so much attention to the subject, I took an important part in the discussions before the Commissioners. The result was the establishment of the code of regulations now in force.

Soon after that time the change began. It was introduced very gradually, and required much caution; but at the present time nearly half the houses are so supplied.

In some districts I believe the change has effected a reduction in the consumption, but in other places this has not been so, a complaint being made of an increase in the waste. I do not know enough of the facts to give any positive opinion as to the causes of this; but I strongly suspect it may arise from a want of proper control over the plumbers and the fittings used, for I was obliged to point out that the character of the plumbing trade in London was, in my opinion, the greatest obstacle to the introduction of the new system. But I am confident that the difficulty may be got over, and I should hope, for the credit of our London water engineers, that the time will not be far distant when the metropolis of England will be as well supplied as Nottingham and Norwich and Manchester have been supplied for the last quarter of a century.

It cannot be denied that the provisions for constant service involve a little more outlay, both to the suppliers and the consumers; but this is largely outweighed by the advantages to

parties. The suppliers have to go to somewhat greater expense in their service reservoirs and in their mains, so as to provide efficiently for the fluctuations in the demand at different times in the day, as I have before explained. But they may reap an enormous advantage in the saving of waste, which will most unquestionably be effected, if the system is carried out vigorously and thoroughly. The experience of all towns where constant service has been effectually acted on is positive, that under this system the consumption may be reduced to the minimum possible, while under the intermittent plan it is always extravagant and wasteful.

Then the consumer has to incur a little more cost for fittings of more perfect character and of better quality, but he gets amply repaid, not only in the greater purity and wholesomeness of his supply, but in the freedom from accident, and the less necessity for repair. For, the very essence of the improved fittings is their less liability to derangement and their greater durability.

PERFORMANCE OF STEAM-ENGINES.

By JOHN W. HILL, M. E.

Much has been written upon the subject of steam-engine economy, as affected by various degrees of expansion, in one and more cylinders, and hot disputes have been observed between exponents of high and low expansions, each having proved by experiment that the other was wrong.

Similarly the benefits of steam-jacketing are disputed by many capable, experienced engineers, and compounding regarded as an unnecessary expedient for economy.

It is true that the data upon which these contrary opinions are based, are not from engines alike in all respects, except in the expansions of steam employed, in the use or disuse of steam-jackets, or in the arrangement of single cylinder or compound steam end, but are from different engines of dissimilar powers, operating under different and sometimes widely varying steam pressures and piston speeds, some from steamship performance, others from engines driving mills, and still others from engines pumping water for cities. It is probable in these cases, where low expansion has given better results than high expansion, that the steam pressures or piston speeds have not been favorable to high expansion, or that the condition of the steam, by reason of considerable entrainment, forbid high expansion; or that the cylinders were not properly clothed, assuming that in all other respects the engines were in good condition.

In these instances, where steam-jacketing failed to show an improvement in economy, it is likely that the steam was of poor quality, or the exterior of jackets poorly protected against loss of heat by conduction and radiation, or the grade of expansion too low to make the benefits of steam-jacketing available.

In these instances where single-cylinder engines have given a higher economy than compound engines, it is probable that the grade of expansion for the compound engine has been too low, that the effect of intermediate expansion may have been overlooked in proportioning the engine; that the relative proportions of steam cylinders were not adapted to maximum economy, or that the division of work between the two (or more) cylinders was not fairly made.

It is, of course, assumed that in every instance where the performance of a steam-engine has been the basis of an opinion upon the conditions best calculated for maximum economy, that the engine *per se* and its connections have been in fit condition for test purposes, and that no losses existed which were unknown and unaccounted for.

The writer, from many experiments upon first-class engines for various purposes, ventures the opinion that high grades of expansion, steam-jacketing, and compounding of steam end are desirable,

if the conditions under which engines are to work are properly considered in fixing proportions, with the following suggestions as to application.

1st. Expansions: The economy of steam-engines, other things equal, will vary as a function of the expansion, provided the terminal pressure be but slightly below the atmosphere. When, however, high expansion can be had only by producing a terminal pressure much below the atmosphere, then the economy will not be materially increased above that due a lower grade of expansion, while the effective work of the engine will be greatly diminished.

Of two cases of high speed engines with similar initial pressures, say, 90 pounds by gauge, and otherwise, operating under similar conditions, where the first shows an operation of the engine with 20 expansions and 4.75 pounds terminal pressure (absolute), and the second, 8.5 expansions, with 12 pounds terminal pressure (absolute), the economy in the second case will be the highest.

Assuming that steam pressures under existing practice be limited to 140 pounds by gauge, or 154.5 pounds absolute, then maximum economy will be had with 14 to 20 expansions of the steam.

2d. Steam-jacketing will not be found advantageous in single cylinder engines operating under less than eight expansions, nor in compound engines operating under less than ten (10) expansions. Moreover, the external wall of jacket space must be thoroughly protected by a non-conducting covering to prevent abstraction of heat from the jacket steam by the atmosphere.

In regulating the consumption of steam by the jackets, care should be had that not more than 5 or 6 per cent. of the total steam to engine be so expended, otherwise the use of the jackets may show a loss rather than a gain.

Under favorable conditions the consumption of steam in the jackets should not exceed 3 to 3.5 per cent. of the total steam to engine.

3d. Compounding: For engines operating at piston speeds of one hundred to four hundred feet per minute compounding will be found beneficial, but for high piston speeds of 600 or more feet, the single cylinder can be made to furnish the best economy.

In compounding, however, consideration must be had for the number of expansions of steam that will occur. No benefit will be found in compounding for an engine working at six or less expansions.

Of the two steam-engines the performance of which forms the substance of this paper, one is a horizontal tandem compound Corliss engine, built from designs by Mr. Edwin Reynolds, of E. P. Allis & Co., Milwaukee, Wis., and the other, a horizontal single-cylinder Corliss engine, built by Wm. A. Harris, of Providence, R. I.

The comparison between these engines is not made to show that either builder constructs a better engine than his competitor, but to exemplify a few of the previous suggestions upon compounding of steam ends, and ratios of expansion.

The tandem compound engine was constructed by Mr. Reynolds, as an experiment, and placed in the "Daisy Roller Mill," an establishment in Milwaukee, the property of Messrs. Allis & Co.; where the designer had unusual facilities for testing the engine, with a view of securing information which might be made beneficial to his customers in the construction of future cut-off engines.

The writer was employed to test this engine and report its performance to Messrs. Allis & Co., with the results given in the following excerpt from his report at the time:

"The engine is a Reynolds-Corliss of the compound condensing type, with cylinders set tandem—small cylinder nearest the crank. The small cylinder has a diameter of 14 inches and a stroke of 42 inches, and the large cylinder, a diameter of 26 inches and a stroke of 42 inches. Both cylinders are unjacketed; but were protected from loss of heat by a plastic covering encased in a lagging of walnut.

"Two trials were made, one from 8.45 A. M., April 26th, to 4.45 A. M., April 27th, 1882, embracing a period of twenty (20) hours, and the other from 11.45 A. M., April 29th, to 12.00 midnight, same date, embracing a period of twelve (12) hours and fifteen (15) minutes.

"During the first trial the engine was operated for the ordinary requirements of the mill, which load being evidently

too light for maximum economy, an effort was made to increase it for the second trial by means of a small friction brake on the line shaft, which, however, was not sufficient to furnish the additional load required.

"In the accompanying table are given the principal dimensions of the engine.

Small cylinder, diameter piston	14.	inches.
" " rod front	2.9375	"
" " " back	2.8125	"
" net area piston front	147.161	sq. in.
" " " back	147.726	"
" clearance per cent. of piston displacement	2.84	
Large cylinder, diameter piston	26.	inches.
" " rod front	2.8125	"
" net area piston front	524.718	sq. in.
" " " back	530.93	"
" clearance per cent. of piston displacement	4.	
Stroke	42.	inches.
Volume of first cylinder, including clearance	3.6855	cu. ft.
" second " "	13 343	"
" receiver and connections	11.1008	"
Ratio of second cylinder to first cylinder	3.6204	
Ratio of receiver to first cylinder	3.01202	
" " second cylinder	0.832	
Volume of steam exhausted at terminal pressure, per revolution	26.521	cu. ft.
Volume of steam retained at counter pressure, per revolution	2.3054	"

"Steam was furnished by a Babcock & Wilcox boiler. The water supplied to the boiler was drawn from the overflow of the condenser and measured in two small tanks, the delivery of which was connected with the boiler feed pump. The tanks were filled to an overflow pipe and drawn down to the lower edge of the outlet pipe.

"The capacity of the tanks was determined by filling and weighing at an observed temperature; from which the weights of water at temperatures of overflow were estimated. All water delivered by the tanks was pumped into the boiler, except as otherwise noted.

"Calorimeter observations of the quality of steam were frequently made during each trial. The weighing scale used for the first trial was not very sensitive, and the first set of calorimeter data is rejected as unreliable.

"Observations were made regularly every fifteen (15) minutes of the boiler gauge, receiver gauge, vacuum gauge, temperature of feed-water; hourly observations were made of the counter, and bi-hourly observations were made of the temperature of injection. Indicator diagrams from both ends of both cylinders were taken quarter-hourly.

"In the following table are given all the material data from the trials.

	Date of Trial.	
	April 26.	April 29.
Duration of trial hours.	20.	12.25
Average boiler pressure pounds.	78.49	92.99
" receiver pressure "	4.2266	8.702
" vacuum inches.	26.503	26.688
" " pounds.	13.0108	13.1016
" barometer inches.	29.5675	29.66
" " pounds.	14.5152	14.5606
" temperature of injection degrees, Fahrenheit.	53.10	54.583
" " " overflow " "	92.256	95.245
" " " air " "	72.150	71.250
Revolutions during trial	91424.	55856
" per minute	76.187	75.9946
Piston speed " feet.	533.309	531.9946

	Date of Trial.	
	April 26.	April 29.
From the Diagrams.		
Initial pressure, first cylinder.....above atmosphere.	76.638	90.698
Counter pressure "	3.9474	8.7135
Mean effective " ..... front.	27.59	25.315
" " ..... back.	27.618	28.2048
Initial pressure, second cylinder.....	0.05312	7.5232
Terminal pressure, " ..... absolute.	4.7339	4.709
Counter " " ..... "	3.1902	2.9416
Vacuum realized "	11.325	11.619
Mean effective " ..... front.	5.388	6.617
" " ..... back.	4.88375	6.7933
Indicated Power.		
First cylineer..... front.	32.808	30.0266
" ..... back.	32.967	33.5828
Second cylinder..... front.	22.845	27.9849
" ..... back.	20.952	29.0706
Total indicated horse-power.....	109.573	120.665
Expansions.		
Cut-off, including clearance, first cylinder.....	0.2176	0.19767
Expansion by volumes.....	21.3231	23.3746
" " pressures.....	19.2554	22.3526
Frictional Resistances.		
Between boiler and first cylinder.....	1.852	2.292
" first cylinder and second cylinder.....	3.894	1.190
" condenser and second cylinder.....	1 6858	1.4826
Economy.		
Total water pumped into boiler.....pounds.	38623.778	25869.98
Leakage caught from safety-valve..... "	32.	50.
Leakage by break of water-gauge..... "		221.182
" caught from feed pump..... "		5.
Consumed by calorimeter..... "	245.	134.25
Percentage of water entrained.....	6.3043	6.3043
Weight " " .....pounds.	2417.433	1605.046
Net steam to engine..... "	35928.345	23854.502
" " .....pounds per hour.	1796.417	1947.306
Steam per indicated horse-power..... " "	16.395	16.138
Calculated Economy.		
Coal per indicated horse-power evaporation, 9 to 1.....	1.8217	1.7931
Steam per hour accounted for by the diagrams.....	1480.449	1482.702
Percentage of steam accounted for	82.4112	76.1412
Steam per indicated horse-power per hour by the diagrams ...	13.5113	12.2877
Performance of Boiler.		
Coal burned during trial.....	6640.	3862.5
Apparent evaporation per pound of coal.....	5.8167	6.6977
Actual evaporation per pound of coal.....	5.45	6.2754
Temperature of feed water.....	119.772	95.245
Steam per pound of coal from and at 212° Fahrenheit.....	6.1647	7.2779
Ash and clinker weighed back	1072.5	446.
Percentage of combustible.....	83.8479	88.4533
" " ash and clinker.....	16.1521	11.5467

"The economy of engine does not vary greatly between the two trials, the second trial developing the better results."

In view of the low percentage of steam accounted for by the diagrams, in both trials, the writer is inclined to think there were some serious leaks, either through the engine or in the boiler, unknown at the time of trial. Allowing a fair loss unaccounted for between the boiler and the engine, the consumption of steam per indicated horse-power per hour should have been for the first trial 15.01 pounds, and for the second trial 13.655 pounds.

Setting aside the theoretical deduc-

tions for economy which are open to criticism, the fact remains that with the unusually high expansions employed in these trials the economy shows no improvement upon that of the single-cylinder engine (operating with one-third the grade of expansion), the performance of which is detailed in the following extract from the writer's report to the proprietors of the mill in which it was running:

"The engine, 24″ diameter of cylinder and 60″ stroke of piston, is condensing and fitted with the ordinary jet condenser and reciprocating air pump.

"The injection water is obtained by a lift of 15′ from the Mississippi river, upon the bank of which the mill stands; and during the trial the condensing water entered the injection pipe, at a temperature near the freezing point. The steam valves were formerly closed by the usual weights; but previous to the trial, vacuum dash pots were added to insure a prompt closing of the valve when liberated from the hook. The engine is furnished with a pulley fly-wheel 20′ diameter and 32″ face; driving back to the line shaft with a 30″ double leather belt.

"The exhaust of engine is closely connected to the condenser by a 10″ pipe, and steam is conveyed from the boiler by a 7″ pipe.

"The feed-water is taken from a drop leg in the overflow pipe from the condenser, and conducted to the suction of a single-acting plunger pump driven from the engine by belt.

"The entire net power of engine is expended in driving the machinery of the mill, which consists of twelve run of 54″ buhrs and three run of 48″ buhrs; two crushing rolls, each with three 12″×30″ cylinders; five rolls, each with two 12″×30″ cylinders, and one roll with two 12″×18″ cylinders.

"The bolting machinery consists of one chest with two reels; two chests with three reels; one chest with six reels, and one chest with eight reels; in all twenty-two bolting reels and forty-eight conveyors.

"The cleaning machinery consists of two 'cockle' machines; one 'scouring' machine; one 'separator,' and two brushing machines. Of the purifying machines there are seventeen, and one shaking machine; four flour packers; four stand of wheat elevators; four stand of flour elevators, and twenty-one middlings elevators. One small and two large exhaust fans.

"To this should be added the machinery of the grain elevator, which is driven by belt from the third story of the mill, and the line shafting, connecting belts, pulleys and gearing forming the general machinery of the mill.

"In the following table are given the principal measured and calculated dimensions of engine.

"The clearance was not measured, but estimated at three per cent. of piston displacement, this being the usual clearance in Harris-Corliss engines of like dimensions.

"The valve functions have been measured on the diagrams.

"The volume of steam accounted for to release is obtained by taking the mean area (feet) of piston into the piston travel (feet) per hour to point of release, to which is added the hourly volume of clearance. The volume of steam retained by exhaust closure is obtained by taking the mean area of piston, in feet, into the travel of piston, in feet, per hour, from exhaust closure to end of stroke, to which is added the hourly volume of clearance.

"The trial of engine for economy of performance was made March 13; all preparations having been completed, the trial began at 9.15 A. M., and terminated at 7.15 P. M.; duration, 10 hours.

"The load was that usually carried in the daily operation of the mill, and was held quite uniform during the ten hours' run. It is possible that the mean power developed was slightly greater than usual, from the fact that the operatives were cautioned to avoid breaks in the load, and that they obeyed the injunction is best attested by the indicator diagrams, which exhibit but slight variations in the mean effective pressure during the economy trial.

"The diagrams were taken by independent indicators, one to each end of cylinder. Forty-pound springs were used, and the drums were moved by well-constructed bell cranks, and reciprocating connections hung on a stout gallows frame. The joints of the levers and connections were carefully made, and means were provided to take up wear, and avoid lost motion.

DIMENSIONS OF ENGINE.

Diameter of cylinder	24 inches.
Stroke of piston	60 "
Revolutions per minute during trial	59.616
Piston speed " "	596.166 feet.
Factor of horse-power due area and velocity of piston	8.204
Piston stroke to release in parts of stroke	99.370
Piston stroke to exhaust closure in parts of stroke	6.067
Clearance (estimated) in parts of stroke	3.000
Volume of steam to release per hour	115038.04 cubic feet.
" " retained by cushion per hour	10189.02 "
Diameter of air pump	12 inches.
Stroke " "	15 "
Diameter of driving pulley	20 feet.
Face " "	32 inches.
Weight " "	40,000 pounds.

"The strings on the indicator barrels were only long enough to couple with the pins on the short-stroke reciprocating bar, and the recoil springs were adjusted as nearly as possible to the same tension. The length of diagrams was uniformly 4.78″.

"During the trial a pair of diagrams were taken regularly every fifteen minutes, making eighty-two diagrams, from which has been obtained the initial pressure in cylinder, piston stroke to cut off, ratios of expansion by pressures and by volumes, terminal pressure, counter pressure at mid stroke, utilization of vacuum and mean effective pressure on the piston, from which is obtained the mean power developed.

"The vacuum in the condenser and the pressure in the boilers were taken from gauges in the engine-room regularly every fifteen minutes.

"The temperature of water to the condenser was taken in the river at the mouth of the injection pipe. The temperature of overflow from the condenser was taken in the measuring tank. The temperature of feed to the boiler was taken in the feed pipe near the check valves.

"The water to the boilers was measured in the following manner:

"Two oil barrels were carefully washed inside and placed on the same level in the engine-room; to the bottoms of these was connected, by branch pipes, the suction pipe of pump; each branch being provided with an open-way cock to shut off the flow when the level had been reduced to the lowest gauge point.

"The pipe from the hot well to the pump was cut and carried out over the barrels; a connection made by branches to each barrel, and a stop valve in each branch regulated the flow of water into the tanks. The tanks, or barrels, were numbered 'one' and 'two,' and were alternately filled to the overflow notch in the rim, and emptied to the center of the branch pipe in the side of barrel, and the contents discharged into the pipe leading to the pump.

"Whilst the number one barrel was running out, the number two barrel was filling with water from the hot well, and directly the first barrel was emptied to the lower gauge point, it was turned off, and the second barrel turned on, and so on during the entire trial; the empty barrel being shut off before the full one was turned on, to prevent transfer of water from the full to the empty barrel. Directly each barrel of water was turned on, the time was entered in the log, and a tally made by the assistant in charge of the tanks. From time to time the writer's record of tanks discharged was compared with the assistant's tally to avoid error in the count.

"After the trial the capacity of each tank was determined by filling to the overflow notch, noting temperature, drawing off to the lower gauge point and weighing.

"The temperatures of the tanks of water discharged into the suction pipe of feed pump having been regularly noted during the trial, the weight of water delivered to the boiler was deduced from the number of tanks discharged, into the weight of tanks at mean observed temperature.

"The calorimeter tests of water entrained were made by drawing off from the steam drum, near the pipe to the engine, a given weight of evaporation, and

condensing it in a given weight of water, noting the temperature of water before and after the steam was turned in, and the pressure of evaporation each time an observation was made.

"Twenty calorimeter observations were made during the ten hours' trial.

"The revolutions of the engine are nominally 60 per minute; but from the ten hours' continuous record by counter, the mean revolutions per minute were 59.616.

"In the following tables are given the observed and calculated data, illustrating the performance of engine and boilers. All data from the diagrams are means of eighty-two readings, and all other data are means of forty-one readings.

"The economy of engine by steam and by coal is developed from the mean quantities charged per hour."

DATA FROM TRIAL OF ENGINE.

Date of trial	March 13, 1879.
Duration of trial	10 hours.
Mean pressure by boiler gauge above atmosphere	92.876 pounds.
" initial pressure above atmosphere	89.376 "
" terminal pressure, absolute	12.018 "
" counter " "	2.696 "
" cut off in parts of stroke, apparent	15.560 "
" " " " actual	18.019 "
" vacuum by gauge	26.40 inches.
" " diagrams	24.05 "
" temperature of injection	33.840°
" " " hot well	92.725°
" effective pressure	32.9792 pounds.
Indicated horse-power	270.5796
Ratio of expansion by volumes	5.549
" " pressures	8.643

ECONOMY OF ENGINE.

Total water per hour to boilers	5037.128 pounds
Water (steam) per hour to calorimeter	10.000 "
" entrained per hour in the steam	655.583 "
Net steam per hour to engine	4371.545 "
Steam per indicated horse-power, actual	16.156 "
" " " by the diagrams	13.035 "
Percentage of steam accounted for	80.682
Coal burned per hour	535.0 "
Coal per indicated horse-power per hour	1.9772 "
" " " evaporation 9 to 1	1.7950 "
Combustible per indicated horse-power, per hour	1 8328 "

PERFORMANCE OF BOILERS.

Pressure by gauge	92.876 pounds.
Temperature of feed to boilers	114.324 "
Total steam furnished	43903.58 "
" coal fired	5350. "
" non-combustible weighed back	390. "
Steam per pound of coal	8.206 "
" " " from temperature of 212° Fahrenheit and pressure of atmosphere	9.639 "
Percentage of ash in coal	7.3 "

In both of these trials unusual care was exercised in measuring the consumption of steam, the quality of the steam and the power developed, and conditions considered, they can fairly be compared for economy of performance.

Neither engine was jacketed.

Comparing the initial pressures, expansions and economy, we have the table of results as on next page.

The initial pressure for second trial of compound tandem engine and for single-cylinder engine were substantially alike, but the expansions by pressures varied nearly as 3 to 1, and yet the difference in economy in favor of the tandem com-

Engine.	Initial pressure.		Expansions by pressure.	Steam per I. H. P. per hour.
	Above atmos.	Absolute.		
Compound Tandem, first trial.....	76.638	91.153	19.255	16.395
" " second trial.....	90.698	106.258	22.352	16.138
Single Cylinder.....	89.376	104.876	8.643	16.156

pound is so small as to come within the ordinary error of observation in reading indicator diagrams for power.

The piston speeds varied as 532 for the compound tandem to 596 for the single-cylinder engine, and this is calculated to fortify the writer's opinion, that single-cylinder engines at high piston speeds and moderate expansions will equal, and often surpass, the economy of compound engines, with high expansions and the piston speed usually employed in this type of engine.

If the economy of the single-cylinder engine upon a boiler performance of ten pounds of steam per pound of coal is developed as "duty" for a pumping engine it becomes $\frac{198,000,000}{1.6156} = 122,555,000.$ foot-pounds per hundred pounds of coal. And this is accomplished with 8.6 expansions of the steam; to obtain this same duty with a compound engine at a piston speed of 250 feet per minute, at least eighteen expansions would be required.

A high grade of expansion means larger steam cylinders and more expensive engines, or higher initial pressures and stronger boilers.

Comparing the terminal pressures, vacuums and economy of the two engines, we have the following table:

Engine.	Absolute terminal pressure.	Effective vacuum.	Steam per indicated H.P. per hour.
Compound Tandem, first trial.....	4.734	23.069	16.395
" " second trial.....	4.709	23.668	16.138
Single Cylinder.....	12.018	24.05	16.156

Here it is seen that with a terminal pressure of 12 pounds and 8.6 expansions the economy is equal to 22 expansions with a terminal pressure of 4.7 pounds.

Referring to the previous table of comparison, it appears that an increase of the initial pressure from 76.6 to 90.7 pounds, and increasing the expansions from 19.2 to 22.3 made but a trifling increase (1.5 per cent.) in the economy of performance.

It is probable that had the compound tandem engine been loaded in the second trial to produce about 9 expansions and a terminal pressure of nearly 12 pounds, the economy would have been quite as good, and the effective work of the engine increased over 150 per cent.

AMERICAN HARDWARE ABROAD.—There is not a corner of Europe where American small cast hardware is not on sale. The tool-makers and machinists of Europe—such as Krupp, of Germany; Whitworth and Armstrong, of England, and Hotchkiss, of France, with their vast resources—are unable to produce a Moncky or screw-bar wrench equal to the American wrenches; and consequently they have to import these tools from the States. It is stated that there are no less than 80,000 dozen of them exported to Europe alone every year. It is interesting to note that Charles Moncky, the inventor of this screw-bar wrench, received only $2,000 for his patent, and is now living at Williamsburg, Brooklyn, in a small cottage bought from the proceeds of his sale. In the matter of the common pocket boxwood rules also, the American manufacturers far excel all others.

THE ACTION OF CERTAIN ADMIXTURES UPON PORTLAND CEMENT.

By Professor L. TETMAJER, of Zurich.

Translated from Schweizerischer Bauzeitung, for Abstracts of the Institution of Civil Engineers.

After acknowledging the services rendered by the German cement-makers in the position they have taken up with respect to adulteration, and the value of the investigations of Professor R. Fresenius, of Wiesbaden, the author points out that his own experiments concerning the action of certain admixtures upon cement do not coincide with the results obtained by Mr. R. Dyckerhoff. He states that his researches were undertaken with a view of learning something concerning the subject, and not in order to prove any particular theory. The influence of foreign ingredients upon Portland cement depends upon two sets of operations, which must be kept distinct; the one set being wholly of a physico-mechanical nature, the other involving a chemical rearrangement of the molecules. Both actions may result in an increase in the normal tensile strength of the mortar. The increase of strength in the mortar tests, due to the admixture of various inert, and for the most part, specifically lighter substances, as for instance, finely ground limestone, rests solely upon a reduction of the injurious effects of the volumetric increase, which freshly-ground cements always undergo in a greater or less degree. Possibly, moreover, in the case of certain cements an increase is caused by this means in the superficial area of the binding agent (*Kittsubstanz*), and therefore, an increase also in the density. It can be proved by means of the addition of slaked lime, or lime putty, to cement that the eventual augmentation of the tensile strength in the sand test thereby obtained is in no way caused by a chemical molecular change, due to the addition of such inert substances.

But the facts are wholly different when the Portland cement is mixed with certain finely ground ingredients, containing silicic acid in a state adapted for chemical combination.

Under such conditions a chemical action is set up, whereby, not only the tensile strength of the pure cement mortar, but also that of the equivalent mixture of cement with lime is frequently increased in a surprising degree. From the results obtained by former experimenters there is little room for doubt that when an improvement in Portland cement is brought about by the addition of soluble silica, this can only be attributed to the formation, in the first instance, of colloidal hydro-silicates of lime, the cement itself furnishing the lime needed for the formation of hydro-silicates. It is now pretty generally admitted that Portland cement liberates lime during the first stages of its induration. In proof of this the author states that he has found on large cubes of concrete, made of highly calcined Portland cement, having a specific gravity of 3.1 to 3 2, an efflorescent growth of carbonate of lime, and in the case of a bridge of Portland cement concrete, made for exhibition, by Mr. R. Vigier, while on the abutments, consisting of a mixture of river sand, screened ballast and Portland, there were abundant evidences of the formation of carbonates on the arch, which was composed of a mixture of Portland cement and granulated blast-furnace slag, no signs of the formation of stalagmites, or carbonates could be observed. This later fact is further important as indicating the influence of slag upon cement in works on a large scale. Free lime in the Portland cement, and silicic acid, in a state free to combine, in the added materials, are the essentials and the deciding conditions in the much-talked-of adulteration question.

Guided by his experiments, the author maintains that when, on the addition of foreign ingredients, no diminution takes place in the tensile strength of the briquettes of the mixed material, as compared with those made from the pure cement, with and without the addition of

lime, the cement has been improved by such addition. There can, of course, be no question that such improvement has been effected when the tensile strength of the mixed cement, alone and with lime, is increased to a marked extent.

The action of foreign ingredients upon Portland was examined by the author, with four different substances and five varieties of cement, which were tested at various ages. The tests included, also, an investigation concerning the influence of the use of more or less water, and greater or less ramming into the molds. The substances employed for admixture were, first, pure blast-furnace slag; second, a composite slag; third and fourth, mixtures specially rich in active silicic acid. Trials were first made of the tensile strength of the slags, granulated, and not granulated, mixed only with lime, in order to study the power they possessed of forming silicates, and indurating in the manner of hydraulic limes. In some cases a tensile strength of 23.5 kilograms per square centimer was thus reached in 28 days. Analyses of the slags and cements are given, and a tabulated statement of breaking weights of a series of mixtures and pure cements follows; a large proportion of samples, in which 85 parts of cement, 15 parts of slag, and 300 parts of sand were tested, show a tensile strength considerably in excess of that attained by a mixture of one hundred parts of the pure cement with three hundred parts of sand.

ELECTRICAL TRAMWAY TRACTION.

From "Iron."

The great expense and inconvenience attending the working of tramways by means of horse-power, has led to numerous devices for effecting that object by mechanical means. Tramway traction has, in fact, long formed an attractive subject for the exercise of inventive talent in almost every direction, including, of late years, electricity. The application of this subtle power to the propulsion of carriages, and even railway trains, by no means dates from the recent practical introduction of electricity, inasmuch as, years ago, designs for electrically-driven locomotives for railway work were brought under our notice, although we need hardly say that the locomotives themselves never came into existence. Even in the present comparatively advanced stage of electrical science, invention has not yet reached that point, although by the light of what we have recently witnessed, there is no knowing how soon it may be reached. The stepping-stone, however, must be the tramways, inasmuch as they offer every facility for conducting experimental investigation and practical trials in the present connection. To tramways, therefore, inventors have naturally turned, and our columns in the near past bear witness to several attempts which have been made to solve the question of electrical tramway traction. But in the examples which have hitherto come under our notice, the car has carried a series of secondary cells, and a stationary electrical motor, which has had to drive the car through belting. A decided departure from the practice hitherto followed in this connection has been introduced in an electrical locomotive which we recently inspected. In this locomotive, which has been built for the North Metropolitan Tramway Company, instead of the electro-motor being a fixture, and having motion transmitted from it through belt gearing to the wheels of the car, the motor itself revolves, the motion being transmitted through bevel gearing. The system is the invention of Mr. C. P. Elieson, and the locomotive has been built by the Electric Locomotive and Power Company, of 6 Great Winchester Street, London. The locomotive is similar in appearance to a short tramcar, and carries a secondary battery consisting of 50 E.P.S. cells. This battery is connected up with the electro-motor, the armature spindle of which projects horizontally about 2 feet, and carries at its end a spur wheel, which gears into a fixed

circular rack corresponding to a crown wheel. Thus, when the motor is started, it is, by means of this gearing, rotated, and weighing, as it does, about 7 cwt., it acts as a fly-wheel. A vertical shaft is attached to the under side of the motor, carrying at its lower end a bevel wheel, which gears into one or other of two similar wheels on the driving axle of the engine. This miter gearing is fitted with a friction clutch, by means of which the locomotive can be run either backwards or forwards. The machinery is so arranged that in no case can a speed of 8 miles an hour be exceeded, the ordinary running speed being six miles.

With regard to the store of power carried, it is to be observed that the 50 E. P.S. cells are equal to 280 amperes, and the average consumption is put at 45 amperes per hour. It therefore follows that we have a good six hours' supply of running power in each engine. Both the locomotive and the tramcar can be electrically lighted at night by means of glow lamps worked from the battery without materially shortening the duration of the supply. We recently inspected this locomotive and its working at the tramway company's depot, at Stratford. The limited space afforded by the depot allowed no opportunity for anything like a practical run to be made. The engine, however, alternately drew and pushed one of the company's ordinary tramcars up and down a line of rails with satisfactory results. The operations of starting, stopping and reversing were effectively performed, the mechanism answering readily to the lever. The machinery, in fact, is very simple, and can easily be adapted to the tramcar itself, if it should be preferred, in building new stock; but the object is, of course, to utilize the old stock, and hence, for the present, at any rate, the engine will be a separate vehicle. The arrangements at Stratford for charging the batteries are in keeping with the locomotive as regards simplicity. There is one of Marshall's 12-horse, double-cylinder portable engines, which drives a dynamo, from which the current is led to the locomotive, the latter being run in from the road and placed on a convenient siding. Or even this may be avoided by leading the electric conductor to the road and connecting it up to the locomotive whilst standing there. With regard to the cost, we have no absolute figures to go by, and indeed we could hardly expect them yet. It is, however, stated that the cost of an installation of a charging station and locomotives to replace a given number of horses, and to do the same amount of work, is considerably less than the cost of the horses, harness, and stabling, while the cost of maintenance is put at 40 per cent. less. This is quite conceivable when placed by the side of the statement that four tramcars require forty-four horses to work them, and when it is remembered that the cost of fodder alone for the animals amounts to about £25 per week. On the whole, therefore, it will be seen that the new electrical locomotive gives promise of success; and if, in practice on the Stratford line its performances equal the expectations formed of it, we may look for its adoption there and elsewhere. We understand that the Electric Locomotive Company are negotiating with the Tramway Company to work their new system, now being laid down from Stratford Church to Ilford, entirely by these electrical engines. General Hutchinson, R. E., of the Board of Trade, has inspected the engine, and has expressed his willingness—subject to a few trifling alterations as to the brakes, &c.—to grant a certificate for the locomotive to be run on the roads. We have hinted at the possibility of railway traffic being carried on at no distant period by the means we have been describing. In support of this, we may mention that the officials of one of our railways have interested themselves in Mr. Elieson's invention, and that the Electric Locomotive Company are now building a powerful engine, with the view of demonstrating the applicability of the system to railways. But, whatever may be the result in that direction, there can be no doubt that this system of electrical haulage is specially adapted for use in crowded thoroughfares, where the transmission of electrical energy by means of suspended or channeled conductors is inadmissible.

AMERICAN TOOLS IN COMPETITION.—American augers and auger-bits are used the world over, no other nation being able to compete.

TIDES AND COAST-WORKS.

By THOMAS STEVENSON, President of the Royal Society of Edinburgh, M. Inst. C. E.

Proceedings of the Institution of Civil Engineers.

As regards the very important but also very abstruse subject of the tides, which forms the first part of the matter which has been remitted to me by the Council, I believe it is not expected that I should enter systematically into it, the more so as there are many treatises which fully embrace all the details in so far as the extent of our knowledge and the state of mathematical science enables the investigation to be undertaken. I may refer in particular to the remarkable treatise on the Tides, in the "Encyclopædia Metropolitana," by Sir John Herschel and also to the works of Airy, Laplace, and Newton.

It seems only necessary, by way of preliminary remark, to note the confusion which has been introduced into the subject, by neglecting to take into consideration the large lapse of time, between the passage of the moon across the meridian and the time of high water, due to the inertia of the water, and the irregularities of the shores and bottom of the sea, in connection with what is called the "Establishment of Ports," or what is generally termed the times of high water on the days of full and change of the moon. As is now well known, the tides do not occur synchronously with the passage of the moon across the meridian, but lag behind for about three or four tides. Another great cause of confusion has arisen from the difference which exists between the phenomena of the flow and ebb of the currents and the vertical rise and fall of the tides; and then again there are many tides which are not directly due to the attraction of the moon, but are strictly of a derivative nature, being produced by their simply spreading from the great primary tide, round points of land and islands. Dr. Whewell did much to establish a map of cotidal lines, with the view of extricating the question from those difficulties, and clearing it from the disorder which formerly existed.

It is hardly necessary to notice that, in so far as regards the British coasts, the great tidal wave, after passing over the Atlantic Ocean, splits upon the Western coast of Ireland, and proceeds in two courses, one branch forming a wave which passes through the English Channel, and the other through the channels of the Orkney and Shetland Islands, and that these branches meet each other in the North Sea, near Yarmouth.

I need scarcely point out how large and beneficial is the influence of these tides on the commerce and wealth of the country, by enabling vessels, even of heavy draught, to pass inland from the ocean. But in so far as our subject is concerned, viz., "Lighthouses," "Coast Harbors of Refuge," and "Coast-Protection Works," we have, principally, to consider in what way the tidal current influences such works.

All sea-works are affected beneficially or the reverse by the height to which the tide rises, in consequence of the configuration of the land, and on the velocity, due to the same cause, which the tidal currents assume. So long as the tidal wave is passing through great depths in the ocean, the tidal range is comparatively small, but when it enters a bay or firth, and especially a tidal river having converging shores, very great changes are produced, as in the case of the Wye, at Chepstow, where the tide has been known to rise 56 feet This, viewed as a mechanical question, may be accounted for, as stated by Dr. Whewell, on "the principle of the conservation of force. When any quantity of matter is in motion, its motion is capable of carrying every particle of the mass to the height from which it must have fallen to acquire its velocity; but if the motion be employed in raising a smaller quantity of matter, it is capable of raising it to a height proportionally greater. In bays and channels which narrow considerably, the quantity of water raised in the narrow part is less than in the wider, and thus the rise in such cases is greater." A

familiar illustration of this principle is the simple experiment of plunging a funnel with its wide mouth downwards into a vessel of water, when a jet of water springs out of the narrow end of the funnel to a height considerably above the level of the water in the vessel.

As regards the influence of the tides upon wind-waves, it is obvious that the effect of currents running in opposite directions to waves, whether they are merely of an oscillatory nature, or those greater waves of translation which affect the bottom at greater depths, must necessarily result in violent conflict, and give rise to what are called "Races" in England, and "Roosts" in Scotland, and which may be witnessed on a small scale in all rivers where the outward current meets the sea and encounters the waves caused by on-shore winds.

In some cases this antagonistic action between the tidal current and the waves increases the height and force of the waves on sea-works and on the shore-line, while in other cases it produces the contrary effect, and acts, therefore, protectively as would an outer breakwater of masonry.

A well-developed example of the sheltering affect of the Sumburgh "Roost," near Sumburgh Head, the most southern point of the mainland of Shetland, came particularly under my notice. At one of my visits to that place, I asked the lightkeeper to observe particularly during the next heavy gale, whether the waves which reached the shore while the "Roost" was in full action, were not of smaller magnitude than when the action had ceased; and some time after I received the following remarkable testimony on the subject:—

"We had a very severe gale from the southwest yesterday, and, being the first gale we have had from that quarter since you were here, I paid particular attention to the state of the sea in the West Voe through the day. By daylight in the morning it was blowing very hard, with a most terribly heavy sea rolling into the West Voe and breaking over the top of the banks, while low water lasted. But with regard to what you said to me about the tide in the 'Roost' acting as a breakwater to the Voe, your opinion is right, for, during the last hours of flood and the first two hours of ebb-tide, in particular, a small boat could have gone till within a few yards of the 'Roost,' between the Lighthouse and the Horse Island, although the sea was still in the same raging state beyond the 'Roost,' and as far as the eye could reach towards Fair Isle and away to the west."

I may remark that wherever the land projects far from the general coast line, "tidal races" will be found to exist, because the currents which oppose the passage of heavy waves are there intensified. Probably the best illustrations of tidal and wave action are to be found in the Pentland Firth, which may be regarded as the most dangerous navigation of any on the British coast, presenting as it does, so many "races" or "roosts." Some writers have alleged that these "roosts" are due to the meeting of contrary currents, while many sailors, on the other hand, believe them to be due to shoal water, produced by abrupt vertical changes in the rocky bottom. But the true cause is undoubtedly the large oceanic waves encountering a tidal current running in a direction more or less opposed to their own. For the "roosts" on the west coasts of Orkney and Pentland Firth are known to be worst with ebb-tide and westerly gales, because the Atlantic swell and the current of ebb-tide are opposed; while those again on the east coast are worst with flood-tides and southeasterly swells. The depth of water where the "Sumburgh Roost" runs is not less than 40 fathoms, showing that it is not due to shoal water or to any submerged upstanding rocks.

A further proof of the influence of the tide upon the waves is afforded by the experience derived in conducting coast-works, where it has been found that the time at which waves of abnormal height gave rise to damage, was when the tide running near the shore was at, or nearly at, its greatest velocity. Murdoch Mackenzie, the justly celebrated marine surveyor and hydrographer of last century, remarks, in speaking of the Orkney tides: "that the spring tides acquired a considerable degree of strength in less than one hour after the quiescent state; neap tides are hardly sensible in two hours after still water; the stream is most rapid commonly between the third and fourth hours of the tide."

In cases where the tide runs close to

or near the shore, many examples might be given to show that the damage to harbor and other works took place after the tide had attained its greatest velocity. It is sufficient to refer to Peterhead harbor, where, at two hours' ebb, after vessels had got aground in the basin, three abnormal waves burst over the seaward pier, knocked down the protecting sea-wall, and washed sixteen persons off the quay into the water. The volume of these waves was such as to set afloat again vessels which had already taken the ground. The contractor's agent stated that, at Alderney breakwater, "the heaviest seas and the greatest rush of water over the wall occurred an hour after high-water."

VELOCITIES OF SOME OF THE MOST NOTABLE "RACES."

Names of Places.	Authorities.	Velocity at Spring Tides in Statute Miles per Hour.
Portland Race	Admiralty Channel Pilot	5.75 to 6.9
Open Ocean between Orkney and Shetland	" North Sea Pilot	5.76
Hoy Sound, Orkney	" " "	6.90
Holm Sound, "	" " "	6.90
Sumburgh Roost, Shetland	" " "	8.06
Burger Roost, Orkney	" " "	8.06
Hell Gate, New York, east current	Prof. H. Mitchell	8.50
Doris Mor, Argyllshire	Captain Bedford, R. N.	9.22
Gulf of Corrie Vreckan Argyllshire	" " "	9.83
Roost, near Louther, Pentland Firth	Admiralty North Sea Pilot	10.36
" Swona, " "	" " "	10.36
" Pentland Skerries	" Survey	12.20

Criteria of Exposed Coasts.—As the result of many observations, I regard the following as being descriptive of those parts of the coast which are most liable to the impact of unusually heavy waves. (1) The waves are most destructive when they come in at right angles to the shore line. (2) Their power is increased in proportion as the direction of the main body of the tide approaches to coincidence with the direction of the heaviest swell, and they are probably worst at those headlands on which the tide splits. (3) Where a considerable part of the coast retires, there will be less sea during the strength of the tide, even although the waves come in at right angles to the shore, because the tide keeps outside, following the direction of the regular trend of the coast; but this will probably not hold true of small re-entrant hollows of the shore. (4) Where the line of exposure and the tide current are parallel to the coast, if the tide runs in a line very near the shore, as is the case in short narrow channels, where the velocity of the current is increased, there may nevertheless be an unusually heavy sea.

Level Assumed by Mud as a Measure of Exposure.—In the "Proceedings of the Royal Society of Edinburgh," vol. iv., p. 200, I referred to a feature which will be found of very considerable value in judging of the exposure of a coast. This is the level below the surface of low water at which mud reposes on the bottom. Though at first sight it might appear unlikely that the disturbance of the sea level by wind-waves would be propagated to great depths, there are numerous facts which prove the contrary. Although the absence of mud in any locality proves nothing, because the tide currents may sweep it away, or the geological formation may not produce it, yet its presence seems both a delicate and certain test of the lowest limit to which the disturbance originating at the surface has reached. Thus, as the waves progressively decrease in magnitude in the North Sea between Shetland and the coasts of the Continent, the level of repose of mud progressively rises nearer to the surface, from a depth of 80 or 90 fathoms to only 8 fathoms at the mouth of the Elbe, and to 12 fathoms off the coast of Holland, where ships can take the open beach in nearly all weathers without any protective harbors. If, therefore, we find, in front of a proposed harbor or coast work,

APPROXIMATE HEIGHTS OF WAVES DUE TO LENGTHS OF MAXIMUM FETCH BY OBSERVATION AND BY FORMULAS.

Place of Observation.	Length of Fetch in Nautical Miles.	Observed Height of Wave.	Height due to Fetch calculated from Formula $h=1.5\sqrt{d}$	Height due to Fetch calculated from Formula $h=1.5\sqrt{d}+(2.5-\sqrt[4]{d})$.
		Feet.	Feet.	Feet.
Scapa Flow	1.0	4.0	1.5	3.0
Firth of Forth	1.3	1.8	1.8	3.2
Granton	2.8	4.0	2.5	3.75
Craignure, Sound of Mull	3 5	2.0	2.9	3.9
Granton	6.0	4.0	3.7	4.6
Lough Foyle	7.5	4.0	4.1	4.96
Clyde	9.0	4.0	4 5	5.25
Colonsay	9.0	5.0	4.5	5.25
Dysart	10.0	4 2	4.9	5.5
Invergordon	11.0	3.5	5.0	5.7
Lough Foyle	11.0	5.0	5.0	5.7
Glenluce Bay	13.5	5.5	5.6	6.1
Anstruther	24.0	6.5	7.5	7.7
Lake of Geneva (stated by Minard)	30.0	8.2	8 2	8.37
Buckie	31 0	7.0	8.4	8.5
"	38.0	7.0	9.2	9.2
"	38.0	8.0	9 2	9.2
"	40 0	8.0	9.55	9.5
Macduff	44.5	8.0	10.02	9.9
"	45.5	10.0	10.2	10.0
Douglas, Isle of Man	65.1	10.12	12.0	11.76
Kingstown	114.0	15.0	16.0	15.25
Sunderland, distance measured from Broken Bank	165.0	15.0	19 3	18.15
		149.82	165.57	162.68
Mean		6.5	7.1	7.07

that mud reposes within a few fathoms of the surface, I believe we have in that fact certain ground for concluding that our works will never be assailed by a very heavy sea.

Line of Maximum Exposure.—The effect of the action of waves against the shore must obviously vary with the line of maximum exposure, or in other words, the line of the greatest fetch or reach of open sea, which can be easily measured from a chart. The engineer has then to ask himself in what ratio, to the lengthening of this line, the height of the waves may be expectd to increase. The result of many experiments on canals and on the Firth of Forth in 1850 and 1852 was that the heights of the waves increased most nearly in the ratio of the square roots of the distances in miles from the windward shore, or when h=the height of the waves in feet from crest to trough, d=distance in miles, and a a coefficient varying with the strength of the wind.

$$h=a\sqrt{d}$$

so that the height of the waves increases in a parabolic curve as they leave the windward shore. For short reaches and very violent squalls a modification of the formula is necessary; but in all ordinary cases and ordinary gales the coefficient in the above formula may be assumed as 1.5.

For shorter distances and violent squalls the following formula is more applicable $h=1.5\sqrt{D}+(2.5-\sqrt[4]{D})$.

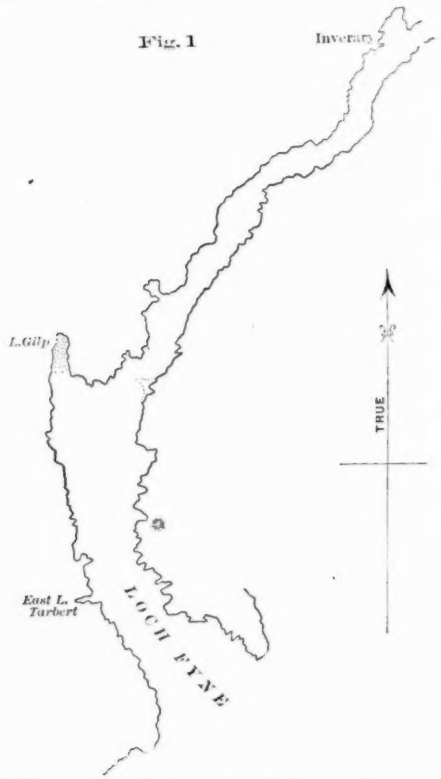
It should be carefully noted, however, that there are modifying elements attending the cases of waves approaching the

land obliquely; for in consequence of the reduction of the depth, they change their directions and approach the general line of the beach more nearly at right angles, and thus strike with greater force than might be expected. There are also exceptions due to geographical configuration of the land. In Loch Fyne (Fig. 1), for example, the wind and waves seem to alter their direction with the winding character of the Loch, so that the effective fetch is greater than the length of free water in the Loch would lead one to expect. In other cases the height of the waves is reduced by increased width of water as at Craignure, in Mull, shown in Fig. 2, where, during the winter of 1853–54, it was less than the formula indicates.

Another modification in the opposite direction is shown in Fig. 3, where the waves which enter a harbor-mouth at B, though apparently generated by the fetch AB, are also largely due to the fetch CB.

Reduction of Height of Waves Occasioned by Shallow Water.—Another all-important matter is the destruction of the waves, or reduction of their height, produced by the shallowing of the water near the shore. That this influence, in the case of heavy seas of the kind called waves of translation, is felt at great depths and at great distances from the coast line, is obvious from a statement by Sir George Airy, that heavy ground-swells have been known to break in a depth of 100 fathoms. The great Atlantic seas, before they break upon any but the most exposed portion of our coasts, have probably suffered a considerable diminution of bulk and decrease of velocity. So soon as the lower extremity of the undulation touches and is

Fig. 1



reduced by a reef or shoal, the upper extremity, by the process which is known as cresting, loses height in proportion. But the wave is not tripped up, and though somewhat lessened and retarded, still continues to rush onward upon the coast. The actual destruction of the wave takes place in shallower soundings. The late Mr. J. Scott Russell, who has conferred so many obligations on the maritime engineer, found that waves break when they pass into water of the same depth as their height, but there are exceptions to this law. In 1870, I noticed at Scarborough, that waves broke when the depth of water was double the height of the wave, the depth being measured below the mean level, and the height from hollow to crest.

Force of the Waves.—By means of a marine dynamometer, the force of the waves was ascertained at Skerryvore Lighthouse in the Atlantic, when during a heavy westerly gale I found that a force equal to nearly 3 tons per square foot was registered; while at Dunbar, where the observations were continued for a much longer period, a force of $3\frac{1}{2}$ tons was registered on more than one occasion.

Fig. 2

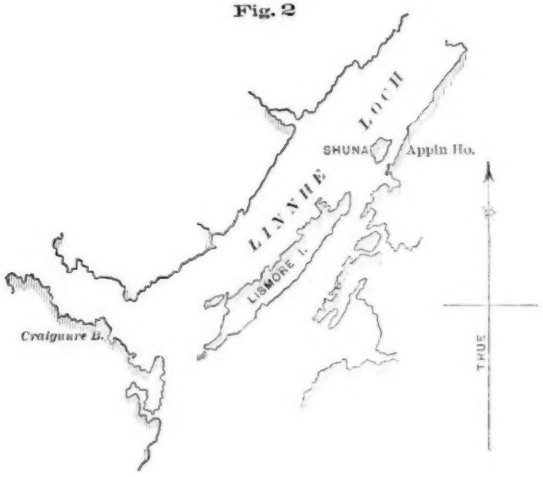
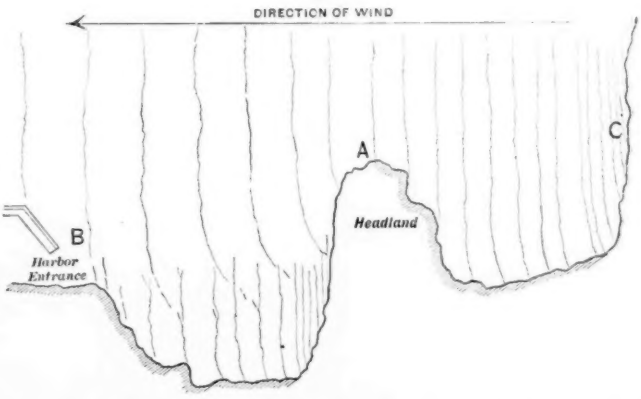


Fig. 3



Coast Works.

The most seaward and most exposed of sea works are generally lighthouses erected on outlying rocks in the sea.

As regards the design of this class of sea works, much as Smeaton's tower has been appreciated, I am distinctly of opinion that, in one very important feature, namely, the outline, the former tower by Rudyerd is decidedly superior for a small rock such as the Eddystone. It is long since I expressed that opinion, and subsequent experience has only tended to corroborate it. I have given general rules in my book on "Lighthouse Construction and Illumination," 1881, p. 28 *et seq.*, which I think will be found useful as a guide to selecting the safest modes of construction.

The profiles shown in Figs. 4, 5 and 6 are suitable in situations where the rock is either soft, hard, or of small dimensions respectively.

Modifying Influence of the Configuration of Rocks on Breaking Waves.—I am satisfied of the great influence exerted by the shape and height of the rocks on which lighthouse towers are built; and I feel bound to take this opportunity of again expressing my conviction that Smeaton's tower should not be regarded as a safe model for imitation on rocks which are exposed to a heavy sea. Nothing less can be deduced from the remarkable fact that the level above the sea at which fourteen blocks of 2 tons each, set and fixed by joggles, dovetails, and cement, were dislodged and swept away by a summer gale at Dhu Heartach, is the same as that at which the thin crown-glass panes of Winstanley's lantern remained unbroken through the storms of a whole winter. It was on this principle, and in consequence of this experience, that a change was made in the original design of the Dhu Heartach, and the solid part carried up to the same level above high water as the lantern in Smeaton's tower.

Fig. 4

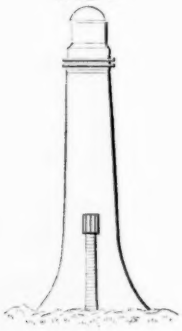
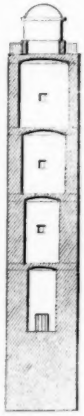


Fig. 5

Fig. 6



The very remarkable cases of wave action exerted at high levels on the rocks at Whalsey, Unst, and Fastnet, are further corroborative of this view.

To decide upon the probable exposure of any rock, and the height of the dangerous impact of waves above high water, many elements have to be considered; the height of the waves, the height and configuration of the rock above and below low water, and the depth and configuration of the bottom of the sea; and it is, unfortunately necessary to add that the influence and relations of these elements have not as yet been sufficiently studied. What may be the effect, whether as shield or conductor, of a given height of rock upon a given height of wave; what may be the effect of such a deep track in the bottom of the sea as that observed by Mr. D. A. Stevenson near Dhu Heartach; or how

much would depend on the direction of such a track, or on the level at which the rock is steep in relation to the height of tide most favorable to heavy seas—are all questions of great importance, still unsolved and well worthy of the attention of the engineer. A rock like Dhu Heartach certainly acts at once as a breakwater against the smaller class of waves, but a dangerous conductor to the heavier. Again, in some observations I made at Skerryvore in 1845, interesting difference were found to exist in wave-force at different levels:

WAVE-FORCES EXERTED AT DIFFERENT LEVELS ON AN EXPOSED PART OF THE SKERRYVORE ROCK.

Date.	Remarks.	No. of Dynamometer.	Pressure in lbs. per square foot.
1845.			
Jan. 7	Heavy sea	No I.	1,714
" 7	" "	No. II.	4,182
" 12	Very heavy swell	No. I.	2,856
" 12	" " "	No. II.	5,032
" 16	Heavy ground swell	No. I.	2,856
" 16	" " "	No II.	4,752
" 22	A good deal of sea	No. I	2,856
" 22	" " "	No. II.	5,323
" 28	Heavy ground swell	No. I.	2,627
" 28	" " "	No. II.	4,562
Feb. 5	Fresh gales	No. I.	856
" 5	" "	No. II	3,042
" 21	" "	No. I.	1,827
" 21	" "	No. II.	3,422
" 24	Fresh breezes	No. I.	1,256
" 24	" "	No. II.	3,802
Mar. 9	Ground swell	No. I.	1,256
" 9	Waves supposed to be about 10 feet high	No. II.	3,041
" 11	Short sea	No. I.	1,028
" 24	Heavy sea	No. I.	2,281
" 24	Waves supposed to be about 20 feet high	No. II	4 562
" 26	Swell	No. I.	1,256
" 26	Waves about 6 feet high	No. II.	3,041
" 29	Strong gale with heavy sea, the highest waves supposed to be 20 feet	No. I.	2,856
" 29	and the spray rose about 70 feet	No. II.	6,083

Two dynamometers were affixed to the rock, No. I. several feet lower, and about 40 feet seaward of No. II.; and, as will be seen in the table, the force registered at No. II. was generally about twice as great as at No. I. It seems to me that it would be of great value, before designing lighthouse towers, to take what may be called dynamometric sections, such as this one taken at Skerryvore, and to examine the results in relation to the varying profile of the rock, and, if possible to different stages of the tide. Such sections it need hardly be observed, will never form a perfect guide in the particular instance, for we shall no sooner have obtained our observations than we shall begin to change the profile of the rock by the addition of the tower itself, and thus to alter the very conditions of what we have been observing. But it is only in this way that I can foresee any chance of our advancing towards sure knowledge of the general law; and I embrace this opportunity of suggesting this course of observation to the younger members of the Institution.

Harbors of Refuge.—The next class of works reckoned seawards on approaching the coast, are those large structures to which the name of Harbors of Refuge is given. They are distinguished from tidal harbors by the generally greater depth of water which they require to possess, in order to fulfill the objects for which they are designed, while the area

which they enclose must also be larger. The requisites are shelter during storms, good holding-ground, and safe access at all times of the tide and in all states of the weather. A breakwater, though a passive, is yet a real agent, having work to do. Many thousand tons of water are raised and maintained above sea level by wind waves, and these waves must either be suddenly stopped, or as suddenly reversed in direction, or else more slowly destroyed within a given space. This is the work assigned to the breakwater, and there are two ways in which it can be done. One way is by means of a plumb wall, which alters the direction of the moving water by causing it to ascend vertically above the parapet of the wall, and then allowing it to fall vertically again, so that the waves are finally reflected and sent back seawards. The other method is to arrest the undulations by a long, sloping wall, so as to give room for the mass of the waves to fall down and destroy themselves upon the surface; but if the slope be not sufficiently long to enable the waves thus fully to destroy themselves, they will, though reduced in height, pursue their original direction, pass over the top of the breakwater, and thus disturb the tranquillity of the harbor. In such a case as this, therefore, the breakwater has failed to do its full share of work, and the necessary amount of shelter has not been produced.

Best Position for Harbors of Refuge.—Opinions have been recently expressed that a harbor of refuge should be placed in a re-entrant part of the coast, and never at any part which is salient. Now, it is of great importance that such a question as this should be fully discussed, as the result must materially affect the interests of commerce and shipping. Various conditions, statistical, geographical and local, should be considered in this question.

(1) *Statistical.*—So far from being necessarily placed in the neighborhood where most shipwrecks have occurred, as has been alleged, or as escape for vessels locally embayed, the harbors of refuge should, in my opinion, be situated as near as possible to the normal track of shipping. Thus, on the occurrence of a gale, a refuge will be ready in a position which can be quickly and safely approached by the greatest possible number of vessels, both large and small.

(2) *Geographical.*—The true situation for a harbor of refuge is rather upon a salient than on an embayed part of the line of coast, because (1), as I have already stated, a salient part of the coast will lie nearer to the line of the general passing trade than a re-entrant part; and (2), vessels seeking a haven and failing to make it, will not find themselves embayed, but be still well to windward, and have sea room to bear away for some more distand haven on either hand. There is, indeed, a sense in which a harbor of refuge in the bottom of a bight may be regarded as a source of danger, instead of a source of safety. Cardigan Bay, in Wales, for example, is just such a place as might, perhaps, be selected. But though a harbor in Cardigan Bay might, in certain exceptional cases, do good, it would be dearly purchased if the presence of the harbor tempted masters to leave the track of safety and unnecessarily to embay themselves. It will, I think, be generally admitted that if, from fog or snow showers coming on, a vessel failed to pick up the position of the harbor in the bay, there would be hardly a chance of her escaping shipwreck. A harbor of refuge on the principle asserted is either kill or cure, for it offers but one chance to the distressed vessel, which she must seek at the cost of embayment; but a harbor of refuge on a salient part of the coast offers a chance of shelter without necessarily compromising the safety of the ship in case she fails to make it.

(3) *The Local Conditions Pointing to the Proper Situation for a Harbor of Refuge are:* (1) The inclosure of the greatest area of sufficiently deep water for the least extent of breakwater to be constructed. (2) The quality of the holding-ground in the anchorage thus to be sheltered. (3) The proximity of suitable material for the construction of the breakwater.

Best Mode of Construction of a Harbor of Refuge.—With reference to the best mode of construction for a harbor of refuge in an exposed situation, there will always be considerable differences of opinion among members of the profession. I shall simply state the form of construction which, on the whole, I con-

sider to be best in situations where the place is fully exposed to the heaviest class of waves.

A very obvious and very important point regarding the stability of such a structure as a breakwater has reference to the depth below low water, at which the waves cease to exert any considerable impact upon the materials on which the superstructure rests. Information of great importance was derived from the history of the Wick breakwater, for

Fig. 7

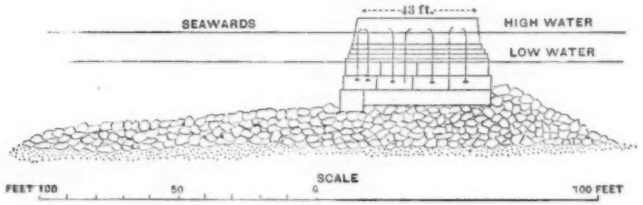
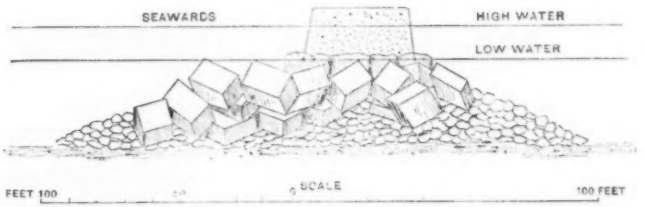


Fig. 8



which my firm were engineers, and which, so far as I have been able to ascertain, was subjected to the heaviest waves that ever assailed masonry. It is sufficient to state that the results which I have obtained, at many different parts of the coast by means of the marine dynamometer already referred to, have been far exceeded by the effects produced by the very anomalous waves which assailed the harbor works of Wick, where the contractor's staging, though consisting of greenheart timber, was found quite unequal to resist the stroke of the sea, and where the heavy rubble which formed the substratum of the work was moved at a depth of about 18 feet below low water. In 1872, a huge monolithic block of concrete, weighing, in all, 1,350 tons, was removed bodily out of its position, and carried to the lee of the breakwater. Extraordinary as this may appear, it was surpassed in 1873, when another concrete mass which had been substituted for the one that was moved, was in like manner carried away, though it contained 1,500 cubic yards of cement and rubble, the weight of which was about 2,600 tons. Yet it is remarkable that after the last damage which took place to the breakwater, when we thought of removing the foundation courses, which were set on edge, we found it impossible to do so, owing to their being so firmly embedded in the rubble base; no part of the foundation of the breakwater was ever moved, nor any of the rubble base ever disturbed, at a lower level than 18 feet under the water. *I am, therefore, of opinion that a level of from* 18 *to* 20 *feet below low-water level may be safely assumed as that of practical stability.* In Fig. 7, showing a section of the end of Wick breakwater, it will be noticed that the bay consists of a sandy bottom, and it is, as I have said fully exposed to the swell of the North Sea. I conceive that the safest and most economic profile of construction, would be as shown in Fig. 8, a mass consisting of rubble extending from the bottom to within 20 feet of low water; when the base had been brought up to this level, blocks of concrete, weighing

from 100 to 200 tons, should be deposited on the top and outer or seaward surface of the rubble base, till they come above low-water level. Betwixt the spaces at the top of these blocks bags of concrete should be placed, so as to form a level platform above low-water level. upon this a solid mass of continuously-built concrete should extend from end to end of the breakwater, which should be not less than 10 feet above high water, and about 45 feet in breadth. I hold that a structure designed on these principles would resist the force of the sea in any situation, provided the sea slope were of sufficient extent. This was the design proposed for the Peterhead Refuge Harbor, and which was approved of by the Committee on Convict Labor.

Mattress Breakwaters, or Training Walls Constructed of Fascines.—There are in many parts of the world bays and arms of the sea of so shoal a character as to cause the waves to break several miles off the shore, but where difficulties of another kind arise from the soft nature of the subsoil; so that although there is no very violent sea to be encountered, yet breakwaters of concrete or masonry are unsuitable, owing to this softness of the bottom, for the waves, reduced though they be, are still able to produce sufficient reaction from the outer face of the breakwaters to plough up the bottom. In order to meet these difficulties, structures called mattresses, which possess peculiar characteristics have been resorted to in various parts of the world, particularly in Holland and America, where they have been found very suitable. In the well-known case of the River Mississippi, for example, Mr. Eads most successfully removed the bar by means of mattresses. The requisites for such structures are that they should be of small specific gravity and of open texture. They must also project but little above the bottom, so as to avoid coming within the direct influence of the breaking action of the waves, and thus to cause reaction, which would endanger the foundations. They must, in short, operate strictly as submarine breakwaters in stopping the action of the waves at the bottom, while they also possess a certain amount of pliancy to enable them to adapt themselves to considerable variations in the level of the bottom, so as to deflect the underwater currents.

Commercial Harbors.—It would far exceed the limits of this lecture were I to attempt to take up the subject of commercial harbors and the like. It may, however, be right to define the great object which must be kept in view in carrying out works of that nature, and that object is to produce a harbor which may easily be taken in rough and stormy weather, without endangering the tranquillity of the internal area; for it is the combination of an easy and safe entrance and exit, with what sailors call a good "loose," and a smooth interior, which alone constitutes a good harbor.

It must further be remembered that a bad result may ensue from devoting an exclusive or too great an amount of attention to one branch of the subject, however desirable the securing of that branch may be in itself; such, for example, as obtaining deep water at the expense of still more important conditions, viz., suitable protecting works and sufficient internal area. The disregard of a due proportion between the internal area and the depth of a harbor has in many instances produced harbors which cannot be said to deserve that name. In order to show how the tranquillity of a harbor may be affected, and how cautious therefore the engineer should be in changing the existing physical relation, I have thought it right to refer to some of the many works which may prove injurious.

Causes of Insufficient Reduction of Height of Waves.—The causes of insufficient reduction of height of waves after entering a sheltered basin may be stated to be too little breadth in relation to width of entrance, or adequate area in relation to the magnitude of the waves outside, also the surrounding of the internal area with vertical walls, and the absence of sufficient length of spending beach to destroy the waves and prevent recoil.

A formula for calculating the reductive power of harbors will be found in my book on harbor construction.

Commercial Value of Depth of Water.—I may state that I have found that the commercial value of harbors or rivers increases as the cubes of the depth of water, although no stated rule can be regarded as more than generally true. The

following formula is designed to apply to this subject when d represents the draught of a vessel in feet; t, the burden in tons; a, a constant depending on build,

$$t=\frac{d^3}{a} \text{ and } d=\sqrt[3]{a\times t}$$

Coast Protection Works.—The last branch of the subject which has been assigned me refers to works which are furthest from the action of the sea, or those for the protection of the land itself.

The physical configuration of the coast-line affords, as everyone knows, a series of the most varied vertical and horizontal profiles. It is generally owing to the effects of atmospheric action, combined with wave action, that such phenomena are due. The two parts of the British coast which best illustrate the particular case of moving of sand and shingle are those of the English Channel and the Moray Firth. I have always been of opinion, I may remark in passing, that the action of tidal currents has nothing to do with the throwing up of shingle on any coast, and the valuable paper of Sir John Coode should, I think, set this matter fully at rest. The breaking of waves at right angles to the coast is quite sufficient to account for the heaping up of shingle between high and low water mark, while the oblique action of the waves sufficiently accounts for the traveling movement of the shingle in the same direction as the heaviest winds. But the cause of the formation of bays or creeks must generally be sought for in the unequal hardness of the different members of the geological formation which confront the sea, and which form a remarkable contrast to the rocky strata or igneous class of rocks which continue to maintain their integrity, from their greater hardness.

The general slope of a fragmentary beach must depend upon the size and nature of the particles and the force of the sea. The great object, therefore, in artificial works of protection is to design the profile of the wall so as to alter as little as possible the symmetry of the beach. Where isolated rocks or large boulders are left projecting above the surface of a sandy shore, there will generally be found around them hollows corresponding in depth and form to the kind of obstruction which the rocks present. The principal point in the design of artificial works of protection is, therefore, to avoid great and sudden obstructions to the movement of the water. The best form that could be adopted in any situation would, of course, be the contour of the beach itself; but this would answer no possible purpose; and as the wall is to consist of heavy blocks of stone instead of minute particles of sand, it is clear that a much steeper slope may be adopted than that which we may call the profile of conservancy of the shore, provided the lower part of the slope be flattened out so as to meet the sand at a low angle. The action of a bulwark is to arrest the waves before they reach the general high-water mark, and to change the horizontal motion of the fluid particles to a vertical plane, or to compel the waves to destroy themselves on an artificial beach consisting of heavy stones. To prevent underwashing, the two following requisites should therefore as far as possible be secured: First, the foundation courses of the wall should rise at a very small angle with the beach, so that their top surfaces may form a continuous curve with the profile of conservation of that portion of the beach out of which the wall springs. Secondly, the outline of the wall should be such as to allow the wave to pass onwards without any sudden check till it has reached the strongest part of the wall, which should be placed as far from the foundation as possible.

Loose Rubble a Good Protection for the Foundation of Bulwarks for Protecting Land from the Sea.—Loose blocks of angular rubble furnish in most cases the best possible security when the soil is soft or friable, for the waves are swallowed up by the interstices. A regular sloping sea-wall or bulwark with a smooth surface becomes, when the soil is soft, a double-edged sword in working its own destruction at top and bottom; for it transfers the duty of destroying the waves from the masonry to the unprotected soil at the top, and to the loose sand or gravel at the bottom of the wall. While the foundations are underwashed by the reaction upon the soft bottom, the upper parts of the masonry are deprived of support by the falling water and spray, which are led up by the masonry, and soon wash away the soil at the top.

Vertical Walls.—For the reasons which have been stated, it is plain that a vertical wall is in most cases unsuitable for a sandy beach. Instead of altering the direction of the wave at a distance from its foundation, the whole change is produced at that very point; and unless the wall be founded at a considerable depth, its destruction is all but certain. Where the materials are costly, but admit of being easily dressed, I am disposed to think that a horizontal, or nearly horizontal, apron or platform of timber or masonry, connected with a vertical wall by a quadrant of a circle of sufficient radius, may be found answerable. Such a form will prevent to a considerable extent the danger of reaction, by causing the alteration in the direction of the wave to take place at that part where the wall is strongest, and which is also at the greatest possible distance from the toe or curb-course. If the materials are abundant and of a rough nature, a cycloidal wall with vertical and horizontal tangents, somewhat similar to that erected at Trinity, near Edinburgh, may be adopted with advantage. But a very serious objection to all forms of curved walls, unless the radius be large, is the weakness which results from the use of wedge-shaped face stones. The impact of the sea upon materials of that form may be compared to a blow directed upwards against the intrados of a stone arch—the direction, of all others, in which the voussoirs are most easily dislocated. This action can only be successfully resisted by very careful workmanship in the dressing and the setting of the backing. Another objection, applicable to all except tideless seas, such as the Mediterranean, arises from the varying level of the surface of the water; for that profile which may be best at one time of the tide cannot be equally suitable at another.

Works for Protecting Land in Open Estuaries.—In other cases in estuaries more open to the sea, works of a stronger kind are required. Figs. 9 and 10 are a plan and section of a protection which was adopted on a line of shore composed of shingle. Jetties projecting from the shore had at first been used to collect the shingle, but in heavy seas the waves were led along the jetties, and had a hurtful effect at their roots where they joined the beach. A continuous line of piling and planking was accordingly adopted, combined with occasional jetties, and this has proved very successful. In proof of this, it has been found that wherever the upright piling and planking have been formed, there was no influx of anything beyond spray upon the adjoining land, but that at all other parts of the coast (which is about 6 miles in length), where the face of the beach is sloping, the water passed freely over in considerable depth, carrying drift timber far into the fields,

Fig. 9

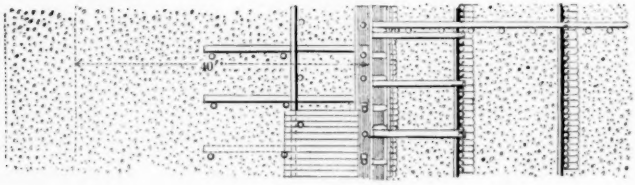
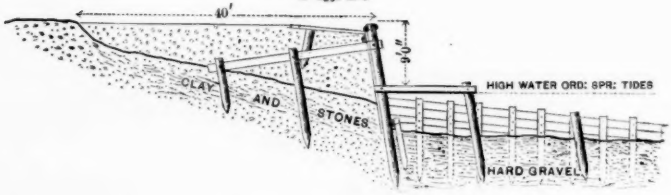


Fig. 10



and in some places heavy shingle to the depth of 2 feet. The problem to be solved was to oppose an obstacle which should throw back the sea; and the upright face, from which the heavy portion of the sea recoils, was found to do this better than the sloping face. In order to encourage the collection of shingle, a second line of longitudinal piling was, at some places, formed in front, and parallel to the main line of defence; and the works now described have been found a very effective defence on a line of shingle beach, exposed to a considerable sea, on the shores of the Bristol Channel.

In designing all such works, however, the engineer must be guided by the formation and exposure of the shores, the kind of materials most easily available, and above all the value of the property endangered, as every engineer must know by experience that in some situations protection can only be secured at a cost out of all proportion to the benefit which it would confer.

The notable difference between the subject to which my attention has been directed by the Council, as compared with the other lectures, is the extreme want of exactness which characterizes the whole subject. In no other branch of engineering is there so great a prevalence of what may be called "rule of thumb." Indeed, hardly any attempt has been made to obtain observations, reducible to a formula, by which numerical results can be calculated as to the force of waves; the height of waves, in relation to the depth of water in which they move; the reductive power of harbors, by which the waves after entrance are diminished in height; the shelter due to protecting breakwaters, and the like. I would strongly counsel young engineers to do their best to supply these *desiderata*. Here is a field where they may do good service to the profession and in the interests of mankind. Here is a branch of engineering where we are still in want of facts, and to a far greater degree in want of the means of scientific calculation. No one knows better than myself the difficulty of the task, for I have had a large experience, and have been too often baffled in my best endeavors to obtain coefficients. But we must not look to difficulty, we must look to utility; and I see no branch where the patience, the ingenuity and the scientific accuracy of observers will be likely to produce more useful results than the one to which I refer. Lastly, I would say a word of welcome to a new book: Mr. Vernon-Harcourt's "Harbors and Docks." It is (particularly on the historical side) a treasury of facts, and forms a large addition to the historical library of the marine engineer.

ENGLISH AND AMERICAN RAILROADS COMPARED.

By EDWARD BATES DORSEY, M. Am. Soc. C. E.

From the Transactions of the American Society of Civil Engineers.

In the opinion of the author, neither the English or American railroad is perfect in itself, if the object of a railroad is to give the greatest amount of comfort to the passengers for the least amount of money, and the cheapest freight charge to the shipper. In this light, the Pennsylvania Railroad comes nearer perfection than any other, but it has the serious fault of many level road crossings. All other large American railroads have, in addition to this defect, that of the absence of the block system. With these two faults alone, they are far from being perfect, to say nothing of minor improvements required, such as good station buildings, etc.

Although the English cars are far from being as comfortable for travelers as the American, yet the English engineer can do but little now to remedy it, owing to the low and narrow cars he is obliged to run. Perhaps the most that could be done would be economizing in the cost of motive power, the general introduction and use of the American baggage-check on all connecting lines, thereby increasing the comfort of passengers, and also saving a large expense to the railroads in saving the cost of many unnec-

essary porters; warming the cars in winter; general use of the bogie truck under passenger cars, thereby diminishing the constant jarring motion now so great in them.

The English road-bed, superstructure and block-signaling system are all that could be desired.

From superficial observation, it is difficult to say what is the cause of the great additional cost in motive power in operating the English railroads, when it should be much less than that of the American railroads, as, owing to their average superior construction, with easier grades and curves, it should not be much over half, instead of being nearly double.

Apparently the most prominent cause of this increased cost is the great speed and small tonnage of the freight trains, and too many passenger trains lightly loaded.

Perhaps the American bogie-truck rolling stock runs with less friction than the rigid wheel-base rolling stock used on the English roads.

The English railroads have cost per mile more than three times as much as the American, yet they only save eight per cent. of the annual operating expenses. In other words, to save one-twelfth of the annual operating expenses, the cost of construction has been increased more than three times. The preceding comparison would be still more striking if we brought into calculation the comparative cost in the two countries of the different items included under the heading of "Maintenance of Way," "Locomotive Charges," and "Repairs of Carriages." Probably 90 per cent. of these are made up of labor, fuel, iron, steel, etc., all of which would average, in 1883, fully one-fourth higher in the United States than in the United Kingdom. This speaks very well for the American system, that, notwithstanding it costs much less to construct, after paying higher prices for labor and materials—and for financial reasons the location is often faulty, and the superstructure of perishable materials—yet it is operated for less than the English roads are, when due allowance is made for the difference in the price of labor and materials that enter into operating expenses. Notwithstanding these disadvantages for similar accommodation, the passenger rates and freight charges are much less on American than on English railroads.

One of the principal items of the greater cost of English railroad construction over the American, is the necessity of having much straighter alignment or easier curves, so that it can be safely operated by the rigid and long wheel-base rolling stock in use there.

The Baltimore & Ohio Railroad is a sample of what can be done with the American rolling stock. This road is built through a very difficult and rugged country, which compelled a very poor alignment, with nearly one-half of the entire length in curvature, which curves run up to 600 feet radii, and long grades running up to 120 feet per mile. The country affords no natural advantages whatever. Yet, with all these drawbacks, this road does a very large and profitable business, paying annually ten per cent. dividend, and running passenger trains safely at very high speed.

All this is done on a road that could not be operated with rolling stock built on the English system. The extra cost of enlarging these curves to adapt them to English rolling stock would be so great as to be commercially impracticable. It is not difficult to appreciate the great difference in cost of construction, in an extremely rough country, of a railroad which curves 600 feet, or 2,640 feet radii.

Unquestionably the American system of construction is the best for new countries, or where cheapness of construction is desirable. The American rolling stock, with the bogie-truck, will run safely and rapidly over roads of inferior construction, or sharp curves that would be impossible for rolling stock constructed on the English type of long and rigid wheel base. The American type is especially adapted for military purposes. During the late American war some military railroads were operated successfully, with the ordinary American rolling stock, with curves of 50 feet radii. The New York Elevated Railroad has been operated for years (it transported last year 97,000,000 passengers) without accident, and has many curves under 100 feet radius. Through an ordinary rough country, a railroad to be operated with the American type of rolling stock could be constructed in one-fourth of the

time, and for one-fourth of the money that one suitable for the English rolling stock could be built.

It would certainly pay the management of the English railroad companies to investigate the cause of the extra cost of motive power on their roads, and, if possible, remedy it. If this can be done, they will be able to *decrease their operating expenses* over 8 per cent., without making any changes whatever in the present prices. This will enable most companies to *increase their dividends* largely—probably over 4 per cent.

For what *is* done in the United States *ought* to be done in the United Kingdom.

CALORIFIC POWER OF FUEL.

By JOJI SAKURAI, Professor of Chemistry, Tokio University, Japan.

From "The Chemical News."

In "Watts's Dictionary, "vol. ii., there is an excellent article on "Fuel," written by Dr. Benjamin H. Paul, where a method for calculating the calorific power of fuel is given. Thus, after speaking of the relative calorific power of hydrogen and carbon, and of the effects of oxygen contained in a fuel, he says on page 723:

"The relative calorific power of fuel may be calculated by means of the following formulæ, in which p represents the relative calorific power, and CHO represent the amounts of carbon, hydrogen, and oxygen in one part of the fuel:

"1. Fuel containing only carbon

$$p=C.$$

"Fuel containing carbon and hydrogen

$$p=C+4.265\ H.$$

"3. Fuel containing carbon, hydrogen, and oxygen

$$p=C-\tfrac{3}{8}O+4.265\ H,$$

or,

$$p=C+4.265(H-\tfrac{1}{8}O)$$

"If it is desired to express the calorific power of fuel in heat units, the amount of carbon and the amount of available hydrogen in one part of the fuel are to be respectively multiplied by the numbers expressing the calorific power of carbon and of hydrogen, and the sum of the two products represents the relative calorific power of the fuel in heat units:

1. $p=8080\ C.$
2. $p=8080\ C+34462\ H.$
3. $p=8080\ C+34462\ (H-\tfrac{1}{8}O)$."

Then he gives a table, in which the relative calorific powers of several combustibles are given, as calculated from their composition according to the above formulæ, and from which I here reproduce a few figures:

Fuel.	Composition of Fuel.				Calorific Power in Heat units.
	Carbon.	Hydrogen.	Oxygen.	Ash.	
Hydrogen.	....	1.00	....	....	34,462
Marsh-gas.....	0.750	0.250	....	....	14,675
Olefiant gas.....	0.857	0.143	....	....	11,849
Av. Welsh coal....	0.838	0.048	0.041	0.090	8,241

The number 14,675, which is the sum of the quantities of heat evolved by carbon and hydrogen separately, is therefore regarded as the relative calorific power of marsh-gas, a view which is similar to stating that marsh-gas is a mixture of carbon and hydrogen.

As everyone knows, the researches of Thomsen and Berthelot have shown us that the calorific power of a hydrocarbon is not equal to the sum of the quantities of heat evolved by the carbon and the hydrogen separately,—that, in fact, we must take into account the heat which is

evolved or absorbed by the separation of carbon and hydrogen from each other. According to Thomsen, the heat of formation of marsh-gas is:

$$CH_4 = +20{,}414.$$

This quantity of heat is therefore absorbed during the decomposition of 16 parts of marsh-gas into carbon and hydrogen, and hence the actual heat of combustion for 1 part of marsh-gas must be about 1,276 units less than the number found in the above table.

Again, when olefiant gas is decomposed into carbon and hydrogen there is *evolved* some heat, and hence the actual heat of combustion of that hydrocarbon must be greater than that in the table. According to Thomsen we have:

$$C_2H_4 = -10{,}880.$$

Hence, the decomposition of 1 part of olefiant gas into carbon and hydrogen evolves about 389 units of heat, and hence the calorific power of olefiant gas should be 12,238 heat units.

Lastly, coal is evidently not a mere mixture of carbon, hydrogen, etc., but is a chemical compound of some sort, and hence the calculation of its calorific power according to the above formulæ is not only useless, but is also erroneous.

There is, so far as I am aware, no formulæ by which the calorific power of fuel may be calculated. The only way is to resort to actual experiments.

It is unfortunate that no correction has been made in the subsequent volumes of "Watts's Dictionary" as to the point above referred to; nor has anyone, so far as I can ascertain, pointed out the error.

Not only is that the case, but even in some of the very recently published books we read similar statements. For example, on page 43, Part II., of Mr. C. J. Woodward's excellent little book called "Arithmetical Chemistry," the following statement occurs:

"The calorific power of coal, of which the percentage composition is given, is calculated in the same way (that is, by adding together the calorific powers of carbon and hydrogen contained in the coal: J. S.), but, of course, any nitrogen or ash the coal may contain must be disregarded; and, further, if oxygen be present in the coal, a quantity of hydrogen or carbon, or the two together, sufficient to combine with this oxygen, must be deducted."

PERIODICAL MOVEMENTS OF THE GROUND AS INDICATED BY SPIRIT-LEVELS. The sixth year (1st October, 1883 to 30th September, 1884) of these investigations presents features almost identical with those of the preceding one; the curve, traced by the east end of the level oriented east-west, shows a gradual fall of 15 seconds to the end of December, 1883; it then fluctuates up and down till the middle of May, having reached its greatest depression, viz., 21.59 seconds, on 24th, 27th and 29th of April. Its subsequent maximum summer rise—reached on 21st–22d September—was only 19.39 seconds. It is worthy of remark, that in four years out of six, the east end has shown not only a smaller subsequent recovery in summer than its fall during the preceding winter, but also an annual diminution in the amount of such recovery, and this agrees with observations made over a period of twenty-three years by Professor Hirsch, at Neufchâtel, where the ground movements indicate three septennial periods, during which the *west* end (not the *east* as at Sécheron) has alternately fallen and risen; but eventually has fallen more than it has risen. The mean annual depression at Neufchatel for these twenty-three years has been 1.59 second, while at Sécheron that of the east end has been 13.44 seconds; if, however, the exceptional cold winter of 1879-80 be omitted, it really amounts to 1.27 second, which is a very fair agreement. Future observations will show if this analogy is maintained, and especially if the septennial periods will also occur at Sécheron.

The oscillations of the ground from east to west in 1884 confirm the remark made last year, that it is the continuity of a certain mean temperature rather than the absolute dates of the maximum and minimum temperatures which influences the epochs of the extreme ground-movements.

The oscillations shown by the level oriented south-north have been as usual less pronounced, their amplitude being 7.26 seconds as against 6.56 seconds last year; and while the south end regularly falls every winter, but gains on this fall little by little each summer, the anomaly of its not following the variations of the air-temperature is still repeated.

THE STEEL PROBLEM.

From "The Engineer."

THE history of steel supplies numerous examples of failure. Mr. Maginnis' experience only differs in magnitude from that of several other engineers. English and Scotch steel are not specially liable to failure. The same peculiarities manifest themselves in American, German, and French steel. Steel makers, in a body, and the majority of steel users, state, and with reason, that, as a constructive material, it is unrivaled for strength and ductility. No one now disputes the accuracy of this proposition. It leaves the solution of the steel problem quite unaffected. That problem is—Why does a material so ductile and so strong split and break? Cracking is the last thing to be expected of it. Toughness is the great specialty of steel. Why should a tough, strong metal crack? This is the question. It does not appear that any answer has ever been given which is accepted as conclusive. To add another theory to the many attempted solutions of the steel problem can do no harm; it may do good.

In this article will be maintained the following thesis: The fracture of steel boiler and ship plates is due not to a defect in the material, but to the homogeneity of the metal. This being the case, so long as steel is homogeneous, so long will fractures such as that of the boilers of the *Livadia*, and many others, occur. Nothing that the steel maker can do will prevent their occurrence, because the steel maker has nothing to do with the immediate cause of failure. This statement is to be taken, of course, with limits; that is to say, the steel must be free from notable percentages of sulphur or phosphorus.

It is evident that steel as a constructive material will always be exposed to stresses. These may be either tensile or compressive; more usually the former. For the sake of simplicity and brevity, attention may be given to only one form of steel, namely, boiler plates. When a boiler plate is in place, it is submitted to a tensile strain, and that strain will not be equally distributed through the plate. It would be easy to show that there can be nothing like equitable distribution of stress anywhere in the plate. It will suffice, however, to point out that the matal between the rivet holes is more severely stressed than the metal in the body of the plate. If this is conceded, it follows that some portions of the plate are more liable to fracture than others, in so far as they are more severely stressed.

It is a peculiarity of all materials of whatever kind, that under anything like a constant stress they give way by degrees. That is to say, one portion parts company with its fellow a little before another portion. The interval of time marking precedence of rupture, may be extremely minute—but we have no reason to say it does not exist. It may also be very considerable. Now, it is a special characteristic of all homogeneous bodies submitted to stress *that if they once begin to give way the process will be continuous until it is complete*, provided the stress be kept up. This is the crucial proposition of the theory now advanced. If it is not true, then all that follows in the way of argument or deduction falls to the ground. It is not true of non-homogeneous materials.

If the proposition be true, a crack, however small, once developed in a steel plate, must continue to extend, if the stress is maintained, until fracture is complete.

If the stress is not severe in proportion to the area involved, the crack may not extend for years. If it is severe, the crack may become a complete fracture in a very short time. For this reason a crack may exist in one part of the steel plate, say in the body of it, which will practically do no harm. A similar crack between the rivet holes may produce the most disastrous results. The magnitude of the crack is of no importance; the magnitude of the stress is. The locality of the crack is only of importance in so far as location determines stress.

In glass we find the analogue of steel. It is homogeneous, possessed of great elasticity and considerable strength. It will stand a stress of about 1.25 ton per square inch. It differs from steel more in degree than in anything else. From this cause all the bad qualities of steel are magnified and intensified in glass. It supplies, therefore, ready to our hands an admirable means of illustrating the truth of the propositions set forth above. We have only to start a minute crack in glass to cause its complete rupture, provided the material is stressed. It may be said here that the force required to fracture glass in which a crack has been started by a diamond is out of all proportion small compared to that which steel will sustain. The answer is that the steel will depend on the cohesive strength of the material. Steel is about thirty times as strong as glass; hence, at least thirty times as much force will be required to develop a minute crack into a fracture. It may be conceded, however, that much more will be needed in the case of steel, and yet the main argument will not be affected. It is necessary here to point out that the magnitude of the initial crack is of no consequence in the case of glass. The crack made by a glazier's diamond is so shallow that its depth can only be expressed in thousandths of an inch.

It must be clearly understood that everything and anything that is called a crack in a steel plate is not necessarily mischievous. There are cracks and cracks. Thus, the crack produced by a glazier's diamond is very peculiar. It is in no sense a scratch. A diamond cannot be cut by a lapidary to produce a crack. A diamond ring will not and cannot "cut" glass; it will only scratch it. The cutting diamond is really a chip or flake of diamond—a natural crystal, in fact—and has not a ground-up, but a natural cutting edge, and it requires some knack in applying it to the glass, even then, to use it successfully.

What may be termed a fatal crack in a steel boiler-plate must be strictly analogous to a crack made by a diamond in glass.

That cracks, once started, will extend in steel has been demonstrated over and over again. Armor-plates afford a good illustration. After one has been struck by a heavy shot, the cracks started by the impact of the projectile will continue to extend, the plate making a peculiar singing noise the while. The special developing powers of cracks in homogeneous mixtures are well known, and provided for in daily practice. Thus, a small hole is punched by the corner of a shutter in a plate glass window; there are minute radiating cracks visible. Leave the pane to itself, and the crack will extend under the influence of the vibration due to street traffic. The prudent owner sends for the glazier, who passes a diamond in a circle around the hole outside the longest of the radiating cracks. The damage will not extend beyond this circle, and the worst that can happen is that the circumscribed piece will drop out, when the hole can be stopped by a new piece cemented in. When a crack starts in a fire box a hole is drilled at each end and a rivet put in. The crack will stop at the holes. It ought to be quite unnecessary to extend illustrations of what must be well known and admitted by all engineers. Mr. J. Head, in his address as President of the Institution of Mechanical Engineers, said:

"The superior tensile strength and ductility of steel as compared with wrought iron, and its independence in these respects of the direction of fiber or grain, arise from its purity and homogeneity. The molecules composing it, when it is in a fully wrought condition, seem to be in almost absolute contact in every direction. There is no appreciable interposition of cinder or other foreign substance, and they are therefore fully subject to cohesive attraction. But this homogeneity is the cause of extreme susceptibility to tearing strains. Imagine for a moment a piece of steel plate to be composed of a number of molecular columns, side by side, each column being equivalent in height to the thickness of the plate. Let us now apply a splitting force just capable of overcoming the lateral cohesion of two contiguous columns forming the edge of the plate at a particular place. They are separated, and offer no further resistance, and the force is available to act on the next pair of columns. These separate, and the split proceeds. The view that mysterious cracks in steel are all in the nature of tears seems to be confirmed by the fact that in such cases

there is never any appearance of contraction at the fractured edges, notwithstanding the general ductility of the metal. This also may, I think, be explained. Let us suppose that one pair of molecular columns in the line of a crack came in its turn under the separating strain, and tended to shorten before parting company. It is evident that the pair of columns last torn apart, and now free from strain, and the next pair ahead, not yet strained, would both act as props, and afford support, so as to prevent shortening of the then strained pair. In this they would be assisted by all other contiguous columns; whereas, if the whole piece of plate were strained equally across while being pulled in two in a testing machine, each molecular column across the line of fracture would be under identical conditions, and none would interfere with the tendency in its neighbours to shorten. Cracks in soft steel plates, unaccompanied by contraction at the fractured edges, must then of necessity be tears; and tears cannot show evidence of contraction. A wrought-iron plate is not liable to tears of this kind, because possibly the cinder which permeates it acts as a sort of padding between the molecular columns. Suppose a similar strain to be applied to the edge of an iron plate, and to leave the first pair of columns separated and just beyond the range of cohesion. If we were dealing with steel, the next pair of columns would now be sustaining the full brunt of the force. But iron being the material concerned, there would be a padding of cinder intervening, and the next pair—or possibly group—of columns would be some distance off. The gap commenced would have to be widened or wedged out, as it were, before the second row or group was strained beyond cohesion; and for this the range of the original force would perhaps be insufficient. To put the case another way. A very finely woven muslin fabric may easily be rent across. But if the threads composing it were rearranged so as to form a coarse net, it would no longer be easily torn, though its combined tensile strength would be unaffected. Mr. Baker, in the course of the paper he read before the British Association, at Montreal, last autumn, said that alarm had been created at the Forth Bridge works by a certain Landore steel plate, $1\frac{1}{8}$ in. thick, which broke like cast iron on being bent cold to the flat radius of 6 ft. He was certain it was not the fault of the material, as a shearing from it had been bent round to a radius of $1\frac{1}{2}$ in., after being made red-hot, and cooled in water. He afterwards traced it to the damage locally commenced by shearing. This could not have extended more than $\frac{1}{16}$ in. from the edge, because planing removed it. Yet it affected the entire width; for the plate 4 ft. 6 in. wide snapped across as easily as a strip 1 in. wide. The difficulty was equally removed by annealing. His practical conclusions were to the effect that the strains initiated by shearing or punching might be fatal to any steel plate, unless removed by planing or rimering, or by annealing. Some time since, a number of steel test pieces were laid on the table of an office adjoining mine, which had all successfully undergone Lloyd's quenching test. That is, each piece had been heated red-hot, then plunged into water at 82 deg. Fahrenheit, and then when cold bent round double, the inner radius of the curve being one and a-half times the thickness of the plate. Several times during the next few days sharp reports like those of a small pistol were heard proceeding from the office. The cause was not immediately detected, but it was afterwards accidentally discovered that some of the test pieces had developed fine cracks across the outer surface of the bend. Although quite sound at first, they had evidently been under severe strain, and their tuning-fork form had caused the sharp report when they gave way. There was no sign whatever of contraction along the fractured edges."

To recapitulate. The failure of steel plates is caused by the formation in them of very minute fissures or cracks of the specific kind needed, and the application of sufficient stress. Thus, for example, a boiler plate is flanged in a ring to take a furnace tube. It is left all night. In the morning the ring is found to have detached itself from the boiler. A little consideration will show that however kindly the metal lent itself to the work of flanging, stresses have been set up in it. The flanging was done while the metal was heated a bit at a time; it was also cooled a bit at a time. We may rest

assured that in such a ring civil war is raging among the molecules. The minority try to break loose; they are constrained by the majority. A fissure of the proper kind, no bigger than a hair, once developed somewhere about the bend and off comes the ring. It will be argued that if this were true annealing would be of no use. This is not so. Annealing is of use, not because it prevents the formation of incipient cracks, but because it demolishes the internal stresses which render the cracks operative for mischief. The stress alone, or the crack alone, will do no mischief. Combine them and an extended fracture is certain to ensue.

Incipient cracks of the right sort occur in iron just as they do in steel; but they have no power of extension. The want of homogeneity in the material is fatal to their progress.

It is very doubtful if any advance has been made toward eliminating the uncertain character of steel. For more than twenty years it has been before the world as a material used for shipbuilding and boiler plates, and twenty years ago it manifested the same admirable qualities it does to-day. It also manifested qualities not admirable; Messrs. Harland and Woolf's experience with the *Istria*, for example. There is, therefore, no reason whatever to imagine that any progress can be made in the means of its production which will render it quite exempt from such failures as those recorded by Mr. Maginnis and "Snap." Neither is it very easy to see how the boiler-makers or the ship-builders can do much more than they do now. Every precaution should be taken to prevent the formation of incipient cracks—which will be quite invisible in most cases—and to get rid of them if formed. Thus the edges of boiler plates should always be planed and *smoothed*. To merely run over them once and tear off a coarse shaving may do as much harm as good. All rivet holes should be drilled, or at least rimered out to a *smooth* surface. The boring out of flanged rings would probably be productive of great good. The utmost caution should be used, in caulking, to use tools in such a condition that they cannot start cracks.

Nothing new is suggested here. The fact that such precautions have long been used is the best possible evidence of the truth of the proposition put forward at the beginning of this article, and repeated here, namely, that the formation of extremely minute cracks in a homogeneous material like steel is certain to cause ultimate fracture, provided stress is put on the plate. The apparently treacherous nature of steel is due wholly to its homogeneous texture, and until for that has been substituted a non-homogeneous or fibrous texture, steel will remain untrustworthy.

ON THE ORIGIN OF ATMOSPHERIC ELECTRICITY.

By E. GERLAND.

Translated from "Elektrotechnische Zeitschrift" for the Institution of Civil Engineers.

The Author first refers to the theories of Mohn, Fick, Pouillet, Dove, Wettstein, Palmieri, Mühry, Becquerel, Werner, Siemens, Holtz, von Bezolds, Dellmann, and other physicists, regarding the source of atmospheric electricity. These theories may be classed under two groups, viz., one in which the earth is taken to be the source of this electricity, and the other comprising all the theories which regard the sun as the origin of the electrical phenomena observed in the earth's atmosphere.

Dove was the first to point out that electricity may be generated by the friction set up when aqueous vapor is formed in the midst of air. This was inferred from the fact that electricity is developed in considerable quantities when sand and dust are whirled about in the air.

Palmieri observed that atmospheric electricity increased as soon as the relative humidity of the air became greater. In the mist, the increase was more marked, and in hail, rain, or snow, the tension became so high that sparks were produced.

To the second group belong the theories of Becquerel and Werner Siemens. The former scientist assumes that the hydrogen given off by the sun is strongly electrified, the electricity in a diminished state of tension being carried into space by radiation until it reaches the earth. Goldstein's experiments have shown that such radiation, analogous to that of light and heat, is possible. Werner Siemens' hypothesis is based on Sir William Siemens' theory of the conservation of solar energy. The basis of this theory is that interplanetary space is filled with highly rarefied gaseous matter, which is drawn towards the polar surfaces of the sun, and during its approach thereto the gases composing this attenuated matter become compressed. On reaching the photosphere, these gases meet with such conditions of temperature and pressure as cause them to flash into flame. The products of their combustion flow towards the solar equator, and are by centifugal force projected into space. Dissociation is then effected by means of solar radiation, and the gases resulting therefrom are again attracted toward the polar regions of the sun, and the cycle of operations repeated.

Werner Siemens assumes that the actions of the gases on the photosphere produces enormous friction, the photosphere thereby attaining a high electric potential of positive sign, whilst the gases become oppositely electrified, and carry this electrification with them into space. As the earth and other planets are probably conductors, each of these bodies forms, in conjunction with the sun, a stupendous collecting apparatus, the insulating medium being the intervening empty space. The potential of the earth is dependent on that of the sun; terrestrial magnetism as well as the northern and southern lights, are mainly due to solar electricity.

Holtz has raised various objections to this theory, and the author points out that it gives no satisfactory solution respecting the source of the electricity of thunder clouds, and does not take into account such phenomena as the diurnal electric variation and, at places where rain is falling, alternate zones of negative and positive electricity surrounding a positively electrified center.

In the author's opinion, these difficulties do not obtain when the earth is taken to be the source of the electricity of clouds, and this hypothesis would have been more generally accepted, had the fact been recognized that the generation of the observed positive electricity of a cloud implied the presence of an equally large quantity having a negative sign. Wettstein and Siemens are the only two physicists who have paid sufficient regard to this, and indicated by what means the negative charge is removed.

The careful observations of von Bezolds show that at the outbreak of a thunderstorm the atmospheric pressure is at a minimum, and the temperature at a maximum. The formation of the storm, is due, therefore, to an ascending current of air, which is capable of rapidly separating the electricities. By means of this upward current warm and humid strata of air are conveyed to colder regions, where the aqueous vapor is condensed with more or less rapidity; this process is accompanied by a development of heat caused by the vapor giving out its latent heat of vaporization. The increase of temperature causes the layers of air to rise still higher, and the vapor becomes more rapidly condensed; raindrops are thus formed, and these drops fall quickly towards the earth. Their velocity relatively to that of the air becomes so great that electricity is generated, either through friction between the drops and the air, or through the formation of the drops, which are charged with electricity of one sign, whilst the air is electrified oppositely. If the velocity of the ascending air-current is sufficiently great, the potential of the cloud may become so high that a discharge takes place between it and other clouds or the earth; the latter having become negatively electrified by induction at that portion of the surface over which the cloud rests. The discharge may be effected gradually by the raindrops, or suddenly with the accompaniment of a flash of lightning, the nature of the discharge depending on the velocity of the current of air. The increased rainfall which often occurs after lightning may be ascribed to a sudden increase in the velocity of the air-current, and a consequent larger formation of raindrops. A greater quantity of electricity is thereby generated, and a sudden discharge to earth takes places, whilst

the raindrops require a longer time to reach the ground. Palmeiri found that the electrification of thunder-clouds was always positive, when no inductive effect was exercised. The phenomenon observed by Dellmann, viz., a cloud with a negative center surrounded by a zone of positive sign, was no doubt due to induction.

The author considers that the various circumstances which precede thunderstorms favor his theory that the source of the electricity is to be looked for in ascending currents of air which cause rapid condensation of aqueous vapor; and he describes, in support of his idea, the various phenomena observed during the thunderstorms of this latitude, which have, according to Dove, their origin in the ascending and descending equatorial currents of air. The author proposes to add to these two classes a third, which shall embrace storms arising from predominant local currents, or summer storms. In Holland, he had, on a stormy evening in winter, the opportunity of observing a phenomenon, which appeared to negative the idea that the electricity of thunder-clouds was due to the inductive influence of the earth. The night was tolerably clear and starlit, when, at a certain moment, a cloud scarcely large enough to cover the constellation of Ursa Major was urged by the west wind quickly across the sky. The cloud had the form of a nine-pin, the point being turned toward the direction from which the wind was blowing. As several flashes of forked lightning passed from the base of the cloud to its point, each flash being followed directly after by loud peals of thunder, the cloud could not have been very distant, or of great extent. No rain appeared to fall from it, but there was scarcely light enough to determine this with certainty. On the supposition that the cloud was charged by induction from the earth, the springing across of the flashes from one part of the cloud to the other could only be accounted for by admitting that a marked change in the electrical condition of the earth took place before each flash, whereas the phenomenon is easy of explanation when attributed to an ascending current of air which caused a small quantity of cold air to be forced into the equatorial current.

THE PANAMA CANAL.

THE following account of the condition of this work is an abstract from a review in *Science*, of the history of the project, by J. C. Rodrigues.

The canal congress estimated the cost of a sea-level canal at 700,000,000 francs, or £28.000,000, although a sub-committee had practically put the cost at 1,040,000,000 francs, and added that the "execution of such works, and principally that of such deep cuts, the stability of which is problematical, as well as the operations relating to the course of the river Chagres, constitute a complication of difficulties that it is impossible to estimate." There was added to the prime cost 25 per cent. for unforeseen expenses, 5 per cent. for expenses of banking and administration, and 3 per cent. per year for interest during construction. An "international commission" visited the isthmus in 1880, and reported that the canal would cost 843,000,000 francs, without preliminary, banking, and administrative expenses, and interest during construction, and estimating contingencies at but 10 per cent. They reported 75,000,000 cubic meters to be excavated, in place of 46,000,000 previously estimated. This estimate of cost M. de Lesseps first cut down to 658,000,000 francs, and later on to 530,000,000 francs. A more extended acquaintance with the problem has raised the estimate of quantity to 125,000,000 cubic meters.

The dredging through the low alluvial lands near the sea, and the formation of harbor works, would, of course, present no difficulty; but the two rock-cuttings —the deepest at the Culebra, 820 feet in width at the top, containing from 25,000,000 to 30,000,000 cubic meters, of which but a small portion has yet been removed; and the Emperador cut, not so

deep, but containing about the same quantity of rock—are very formidable obstacles, which will, at the rate work has as yet progressed, require many years to overcome. There is also the uncertainty whether little or much water will be encountered in the lower portions of these cuts. The removal of rock under water will swell the cost greatly.

The Rio Grand and Rio Obispo cross the canal eleven and seventeen times respectively, and hence must be diverted, calling for thirty miles of new channels. The most formidable obstacle, however, and one which leads many engineers to doubt the possibility of the maintenance, if not the construction, of the canal, is the controlling of the tremendous floods of the upper Chagres—a stream which, in the dry season, has a depth of but two feet, but which, in the rainy season, becomes a raging mountain torrent, rising sometimes in a few hours to a height of 40 feet, and sweeping down immense quantities of *débris*. The projected line of the canal is first crossed by it at Gamboa, at an elevation of about fifty feet above the bottom of the canal; from Gamboa to the sea the canal is crossed by it twenty-nine times. It is evident that some most substantial and expensive works are needed to restrain or divert the flood waters of the Chagres, or the canal will be ruined by its irruption. An immense dam of masonry or earth, or of both materials, has been proposed, near Gamboa, a mile in length and from 150 to 200 feet high at its highest point, to impound and store up the flood in an artificial lake, from which it shall escape more gradually through sluices and channels provided for the purpose. The storage capacity of this reservoir is estimated at 6,000,000,000 cubic meters, which is not too much for a watershed on which a depth of five and one-half inches of rain has been known to fall in four and one-half hours. The occurrence of a second tropical rain, before the first has had time to drain away, might be disastrous. This difficult problem, which was pointed out and dwelt upon by some of the delegates to the congress, but was apparently passed lightly over by the majority, seems still to be unsolved at the hands of the French engineers, although the completion of its study has been promised from year to year.

The Panama railroad was purchased by the canal company; dwellings, hospitals and workshops were erected; dredges, machinery and tools were procured; and excavating was begun. Considerable earth and some rock have been removed. Rapid progress has been promised from time to time, but has not been attained; 2,000,000 cubic meters per month were hoped for, but 800,000 cubic meters have not been removed in any one month, and from 1881 up to May, 1885, the amount was only 12,376,000 cubic meters. The amount of material to be moved was first placed at 46,000,000 cubic meters, then 75,000,000 cubic meters, has now swelled to 125,000,000 cubic meters, and good judges believe this quantity to be much too low. M. de Lesseps has raised amounts as follows: 50 per cent. on the shares of the company, 147,500,000 francs; loan of 1882, 125,000,000 francs; loan of 1883, 300,000,000 francs; and loan of 1884, 193,602,500 francs; making, in all, 766,192,500 francs. He has now applied to the French government for permission to issue new canal bonds to the amount of 600,000,000 francs, and proposes to call to his aid a lottory. A further call on the shareholders is also to be made. Discount and interest charges will amount to a formidable sum. One observer puts the time required to finish the canal at six years, another at twelve, and still others at twenty and even fifty years. Mr. Rodrigues fortifies his statements by citations from official documents, and from reports of United States officers and others, who have repeatedly inspected the progress of the work. He does not hesitate to predict the failure and bankruptcy of the present company within a short time.

THE *Journal of the Society of Arts* describes a plan for rendering paper as tough as wood or leather, which has been recently introduced on the Continent; it consists in mixing chloride of zinc with the pulp in the course of manufacture. It has been found that the greater the degree of concentration of the zinc solution, the greater will be the toughness of the paper. It can be used for making boxes, combs, for roofing, and even in bootmaking.

ON THE EFFECT OF ALTERNATE HEAT AND COLD ON IRON, STEEL AND COPPER.

By EDMUND WEHRENFENNIG.

From "Organ für die Fortschritte des Eisenbahnwesens."

Translated for Abstracts of Institution of Civil Engineers.

It is well known that wrought-iron or steel bars, after being first heated and then suddenly cooled, decrease in length, as well as that in the case of cast-iron the opposite result takes place, viz., an increase in length. Copper, in this respect, behaves in a similar manner to cast-iron. The author made a large number of experiments, with a view of determining the amount of respective increase or decrease in length for special practical purposes, but his researches being extended beyond what was originally intended, he determined to treat the matter more scientifically.

Experiments with Wrought-Iron.—These experiments were made on round bar-iron, ranging from 2.38 inches in diameter to wire 0.04 inch thick. The bars were subjected to different degrees of heat and then suddenly plunged into cold water, or cooled slowly in the air, or in other cases left to cool down under ashes. A series of experiments were made in which, in one case, the iron was heated for five hours, in the second case for thirteen hours, and in the third for eight days during ten hours per day, the furnace cooling down during the night.

Experiments were also made with flat iron and plates.

The following is a summary of the results of these experiments:

1. A higher temperature imparted to the iron produces greater results than a lower temperature.

For example, in the experiments made with bar-iron 1.04 inch × 1.04 inch in section, the diminution amounted to 0.023 per cent. after the bar had been heated to from 570° to 750° Fahrenheit and then plunged into water; whilst in another case, where the temperature to which the iron was subjected exceeded this degree, the decrease in length measured 0.087 per cent.

2. Rapid cooling and great range of temperature increase the amount of diminution.

3. The length of time during which the metal is subjected to a high temperature greatly influences the amount of contraction.

4. The form of the metal is also an important factor, as shown by the following result:

	Inches.				Per cent.	
Round bar-iron	2.36–1.38	diameter,	decreased	in length by	0.069	Mean of thirteen experiments.
" "	0.79–0.67	"	"	"	0.065	
" "	0.31–0.20	"	"	"	0.066	
" wire	0.12–0.07	"	"	"	—0.025	

Whilst, therefore, the heavier section of bars decrease, almost uniformly the wire increases in length.

In the case of two iron plates, one 0.51 in., the other 0.20 in. thick, the former decreased in length and breadth but increased in thickness, while the latter increased in all its dimensions.

Experiments with Steel.—Ordinary steel under the influence of heat and cold behaves in a similar manner to wrought iron, but some steels on being subjected to this treatment neither decrease nor increase perceptibly in any of their dimensions.

The following are the results of experiments repeated three times on a bar of steel of 2.28 in. by 1.18 in. section:

				Per cent.
Diminution of length after	first	time of heating, and then cooling under exposure to atmosphere		0.001
" "	second	"	water	0.125
" "	third	"	"	0.107
" "	fourth	"	"	0.096
Total diminution.....				.329

The author gives an account of several experiments made with steel tires, and proceeds to describe the—

Experiments with Copper.—A copper rod, 5.871 feet in length, with a section measuring 2.18 inches in diameter, together with one iron and two copper wires 0.11 inch thick, and of the same length as the copper rod, were heated to a high temperature and then plunged into water, with the results that,

	Inch.
The copper rod increased in length by..	0.138
" " wires " " ..	0 303
" iron wire " " ..	0.177

Experiments with Cast-Iron.—Bars of cast iron:

23.62 in. long,	7 32 in. wide,	1.65 in. thick.
20.00 "	7.32 "	1.65 "
20.04 "	7.32 "	1.65 "

were heated and then allowed to cool by exposure to the atmosphere, or by plunging into water, thereby producing a mean increase of length of 0.051 per cent.

The behavior of brass under this treatment is similar to that of wrought iron, only more marked.

The rest of the paper is devoted to exhaustive speculations as to the cause of the respective contraction and expansion of the building and warehouses. The two larger kilns, of 1,000 barrels capacity each were oval on plan, and the two smaller ones, of 500 barrels capacity, were circular. The larger kilns had eight furnaces, four on each side, and the smaller kilns four furnaces. The kilns were draw-kilns, or perpetual kilns, 45½ ft. in height, and having a railway running above them, for loading in the cement-stone in 2-ton charges from the mine. The space below the draw-gates is sufficiently large to cool the calcined rock to a proper degree for handling in wooden cars. The kilns are drawn every two hours, and filled with fresh rock once in twenty-four hours. The calcined stone, after being crushed, passes by an elevator to the top of the mill-house. The mills are self-feeding by spouts from above. Instead of running horizontally, they are set edgeways on horizontal spindles. The stones are 30 in. in diameter, and each consists of a single block of the best French burr; the runner has a speed of five hundred revolutions per minute. Each mill, when in good trim, will grind fifteen barrels per hour of the standard fineness. The wear of the stones is so great that they require to be dressed after the grinding of each one thousand barrels, and should preferably be dressed after grinding five hundred barrels. The power for the mill is furnished by an engine of 210 H. P., with two tubular boilers. Rope gear is used to avoid extra engines for hauling. The wire rope, under severe and intermittent strain, runs at the rate of about 2,400 ft. per minute. The ropes are ⅜ in. in diameter, of iron wire with hemp center; the pulleys are 5 ft. in diameter, fitted with rubber filling. Steel wires were first employed, but found not to wear so well as those of iron. Particulars with respect to water supply from an artesian well follow, and also as to the use of water under a 90-ft. head to serve the drills. The following analyses are diven of the rock and of the cement:

I. Analysis of Rock by Professor Blaney, of Chicago.

Carbonate of lime	42.25
" magnesia	31.98
Clay and insoluble silica	21.06
Iron and alumina	1.12
Silica	0.06
Water	1.07
Total	97.54

II. Analysis of Cement by G. Bode.

Lime	33.67
Magnesia	20.98
Alumina	9.92
Silicic acid	35.43
Total	100.00

The highest chimney yet built in the world has recently been completed at the Mechernich Lead Works in Germany. The whole height of the structure is approximately 440 ft., 11 ft. of which is underground. The subterranean portion is of block-stone, 37 ft. square in plan. All the rest is of brick. The plinth or lower part of the chimney above ground is 34 ft. square, so that the height of the shaft is nearly thirteen times the lower diameter. The exterior diameter of the shaft at the top is about 11½ ft. The flue is 11½ ft. at the bottom and 10 ft. at the top. Hitherto the highest chimney in the world has been that of the St. Rollox Chemical Works, near Glasgow. This is 434 ft. high.

ON EXPLOSIVE GASEOUS MIXTURES.

By MM. BERTHELOT and VIEILLE.

Translated from "Annales de Chimie et de Physique" for Abstracts of the Institution of Civil Engineers.

These experiments were made to determine the pressure developed and the heat generated by the explosion of various gaseous mixtures in closed vessels. Tables of results are given, and from them the authors deduce the limits of temperatures of combustion, dissociation and the specific heats of the gases at very high temperatures. The results, methods of experiment and calculation are discussed in eight papers.

1*st. On the Calculation of the Temperatures of Combustion, the Specific Heats and Dissociation of Explosive Mixtures.*—This paper is the continuation of a memoir by M. Berthelot in 1877, and contains a theoretical consideration of the principles which have guided the authors in these investigations.

Given the pressure P, developed by the explosion of a gaseous mixture, the temperature of combustion is determined by the method of limits. In the case of no dissociation, a limit above or equal to the real temperature of combustion is given by the formula

$$t_1 = 273\left(\frac{P1}{Hg} - 1\right),$$

where H is the initial pressure at 0°, and g is the ratio of the volume occupied by the burnt products completely combined to that of the same bodies entirely dissociated. If the initial temperature be above zero, say T,

then $$P\left(1+\frac{T}{273}\right)$$

is used instead of P in this formula, which is deduced from the laws of Mariotte and Gay-Lussac. When there is complete dissociation and none of the products really combined, another limit, t_2, below the temperature of combustion, is found from the equation

$$t_2 = 273\left(\frac{P}{H} - 1\right).$$

The real temperature of combustion lies between these limits t_1 and t_2, which are brought much closer by the presence in the mixture of inert gases, such as nitrogen—in the case of combustion by means of air. Two sorts of systems are considered. Reversible systems, where the compounds formed by combustion can by dissociation be split up into the original components: such are CO_2, forming CO and O, and water-vapor giving H and O. In non-reversible systems dissociation does not produce the original components. Thus a mixture of cyanogen and oxygen, on complete combustion, yields CO_2 and N, whilst dissociation tends to produce O and CO or even free carbon. Knowing Q the quantity of heat generated by complete combustion at constant volume, another limit t_3, intermediate between the preceding ones, is calculated for reversible and a few non-reversible systems. The mean of t_1 and t_4 gives a close approximation to T, the temperature of combustion.

Then the total heat Q divided by the values t_1, t_2, t_4, T, gives a set of corresponding limiting values, c_1, c_2, c_4, C, of the apparent specific heats of the system at constant volume between 0° and T. The apparent specific heat includes the specific heat properly so-called and the heat given up by the recombination of the dissociated components. The mean value C, of c_1 and c_4 represents the specific heat. This applies to such gases as CO_2 and water-vapor, even when mixed with inert gases like N or with hydrocarbons. Thus values of the specific heat at constant volume of different systems are deduced for temperatures ranging between 1,700° and 5,000° on the air-thermometer.

When two elementary gases combine at constant volume without condensation, the ratio of the effective temperature t, to the temperature T which would be produced by complete combustion, that is t_1 T, gives the ratio of the volume of the portion really combined to the total volume, and hence determines the dissociation.

Special stress is laid on the results obtained from a group of isomeric mixtures, *i. e.*, mixtures which contain the same elements in different states of combination, but all yielding an identical mixture after combustion.

2*d. Experimental determination of the Pressures developed in Gaseous Explosive Mixtures at the Moment of Explosion.*—The pressures have been obtained by exploding the gaseous mixtures in spherical vessels, and registering on a revolving cylinder the law of the displacement of a piston of known section and mass. Complete data of two experiments are given, with readings taken off the curves at given intervals of time during each experiment. The cooling effect of the walls of the vessels is observed by exploding the same mixture in vessels of different capacities. The results are fairly concordant with those obtained by Messrs. Bunsen, Mallard and Le Chatelier by entirely different methods, so far as the latter extended. The authors have made numerous experiments with forty-two different mixtures of H, O, N, CO, CH_4, NO, cyanogen, ether, &c., and the pressures are recorded.

3*d. Relative Rate of Combustion of different Gaseous Mixtures.*—Three explosion vessels of different capacities and shapes were employed. The maximum pressure observed when a mixture of gases is exploded in a vessel at constant volume is always less than if the system retained all the heat generated by combustion, the loss of heat being due to contact with the walls of the vessel and to radiation. This difference is greater the smaller the explosive-vessel, or the smaller the mass of gas with respect to the vessel, and it is also greater the slower the rate of combustion. The time required for the development of the maximum pressure is generally longer the larger the explosive-chamber, and the greater the distance between the piston and the point of ignition. CO is slower than H, but for cyanogen and hydro-carbons rich in H, the time is about the same as for H alone, and agrees with the calculated velocities of the explosive waves. The velocity of translation of the molecules governs the phenomenon. Assuming that the flame reaches the piston at the moment of maximum pressure, the absolute rate of combustion is about 100 meters per second for hydrogen, 8 meters for carbon monoxide, and 70 meters for cyanogen. This is diminished by an excess of one of the combustible gases, and even more so by the presence of the burnt products. An inert gas like N retards combustion not only by lowering the temperature and thus diminishing the velocity of the molecules, but also by preventing contact between the molecules which act on one another. With a mixture of carbonic oxide and hydrogen in oxygen, each gas appears to burn separately at its own rate, the hydrogen burning before the carbon, and consequently the maximum pressure observed does not correspond with a uniform state of combustion of the system.

4*th. Influence of the Density of Explosive Gaseous Mixtures on the Pressure.*—If, in a gaseous system to which heat is communicated, the pressures vary in the same ratio as the densities, it follows, independently of all hypotheses on the laws of gases: (1) That the specific heat of the system is independent of its density, that is of the initial pressure, and depends solely on the absolute temperature. (2) That the relative variations of the pressures at constant volume, produced by heat given to the system, is also independent of the pressure, and is a function of the temperature alone. In fact, the pressure itself varies directly as the absolute temperature, and, according to the theory of perfect gases, serves to determine it.

The authors overcame the difficulties attending direct measurements at high temperatures by two methods. One consisted in using a vessel, one part of which was maintained at the ordinary temperature in the air, and the other heated in an oil bath to about 153°, which reduced the density of the gas about a third. The second and more exact method consisted in experimenting on isomeric mixtures. From numerous experiments with isomeric mixtures, under different conditions as to density and heat generated, the observed results confirm the ordinary laws of gases.

The authors conclude that for temperatures up to 3,000° or 4,000° on the air-thermometer:

(1) When a given quantity of heat is communicated to a gaeous system, the

variation in the pressure of the system is proportional to its density.

(2) The specific heat of gases is sensibly independent of the density at very high temperatures as well as at zero.

(3) The pressure increases with the quantity of heat given to the system.

(4) The apparent specific heat increases with this quantity of heat.

5*th. Temperatures and Specific Heats calculated from the experimental results.*—These are calculated by the methods described in the first paper, from the pressure P developed during the explosion, and the total quantity of heat Q generated by the complete combustion of the gaseous mixtures. The mixtures are arranged in four groups, and two tables are given for each group, containing the values obtained for the temperatures and specific heats.

6*th. Specific Heat of the Elementary Gases at very high temperatures.*—The authors agree with Messrs. Mallard and Le Chatelier in the general conclusion, that the specific heat of gases increases with the rise of temperature, and that the simple gases have sensibly the same specific heat at all temperatures. By supposing the increase to be proportional to the temperatures between 2,800° and 4,400°, the authors deduce from their experiments the empirical formula—

$$C=6.7+0.0016\ (t-2{,}800),$$

which gives the specific molecular heat at constant volume of nitrogen, hydrogen, oxygen, and carbonic oxide. Between 0° and 200° the specific molecular heats at constant volume of these gases are about 4.8, and the authors find this number doubled in passing from 0° to 4,500°, becoming 9.8. The variation takes place at all temperatures; it is inappreciable from 0° to 200°, but increases rapidly at high temperatures. The law of increase of the mean specific heat above 1,600° is expressed by the formula—

$$4.75+0.0016\ (t-1{,}600).$$

The real specific heat at constant volume, *i. e.*, the quantity of heat necessary to change the temperature 1°, is calculated by the formula—

$$4.75+0.0032\ (t-1{,}600),$$

for the elementary gases at temperatures from 1,600° upwards.

The specific molecular heat at constant volume of chlorine is greater than that of the simple gases, being 6.6 between 0° and 200°; also at 1,800° the mean specific heat of hydrogen is 5.1, whilst that of chlorine is 15.3. thus approaching that of carbonic acid, which is about 18.

7*th. Specific Heats of Steam and Carbonic Acid at very high temperatures.*—The mean specific heat of steam at constant volume deduced by the authors from their experiments may be expressed by the formula—

$$16.2+0.0019(t-2{,}000)$$

where t is from 2,000° to 4,000°. The mean specific heat of steam at constant volume between 130° and 230° being 6.65, it is doubled at 2,000° and trebled at 4,000°. The heat of formation of water continually diminishes as the temperature rises. This is partly due to the heat spent in the work of molecular separation without decomposition, and partly to the heat absorbed in decomposition or dissociation. About 3,000° dissociation would absorb at most 6,600 calories, that is, one seventh of the heat of combustion, whilst molecular separation would absorb at least 8,600 calories, or about one-fifth of the heat of combustion at this temperature. These numbers are given with all reserve.

The mean specific heat of carbonic acid at constant volume between 0° and t is given by the formula—

$$19.1+0.0015(t-2{,}000)$$

where t is from 2,000 to 4,300. As in the case of water the results show that the heat of combustion of CO to form CO_2 diminishes with the temperature above 200°. The authors calculate that about 4,500° the heat of combustion would be 28,000 calories, and dissociation would absorb at most 18,000 calories, that is, about two-thirds of the heat, whilst at least 22,000 calories of the heat is absorbed by intra-molecular transformation. Comparing the heat of combustion of H_2O and CO_2 at 0°, they are almost equal, being 58,700 calories and 68,000 calories respectively, whilst at 3,000° they become 26,000 and 38,000. Thus their ratio decreases as the temperature increases, and at very high temperatures the carbon tends to entirely decompose the steam.

8th. Scales of Temperatures and Molecular Weights.—The results of the previous Papers are considered. Two air-thermometers are compared, the scale of temperatures of one being determined by the dilatations of volume at constant pressure (or by variations of pressure at constant volume) whilst the scale on the other is determined by the quantities of heat absorbed. At very high temperatures these differ widely from one another, and from similar chlorine—or iodine thermometers, owing to the variations in the specific molecular heats which, especially in the case of chlorine, would point to changes in the ultimate molecular constitution of substances hitherto regarded as elementary.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers—January, 6th, 1886.—Vice-President Geo. S. Greene, Jr., in the chair. The ballot was canvassed upon the proposed amendment to the by-laws, substituting in section 24, clause 5, the word "December" for the word "November." The clause will then read:

5th. "Any five members, not officers of the Society, may present to the Board of Direction, on or before December 1st, a list of names proposed by them for officers, which list or lists shall also be issued for ballot."

There were in the affirmative 142 votes, and in the negative 4 votes. This amendment was declared adopted.

The following candidates were elected: As members—Maximilian Ferdinand Bonzano, of Philadelphia, Pa.; Franklin Ide Fuller, of Portland, Oregon; George Watson Kittredge, of Zanesville, Ohio; Henry Wadsworth Reed, of Waycross, Ga.; Henry Frederic Rudloff, of Caracas, Venezuela, S. A.; Albert John Scherzer, Sonsonate, Salvador, Central America. As associate—Calvin Tompkins, of New York City. As Junior—Harry Lee Van Zile, of Troy, N. Y.

The paper previously presented by Mr. Jos. M. Wilson, M. Am. Soc. C. E., on Specifications for the Strength of Iron Bridges, was then discussed. Written discussions were presented from Messrs. William H. Burr, Mansfield Merriman, S. W. Robinson, George F. Swain, G. Bouscaren, Mace Moulton, A. P. Boller, George H. Pegram, William Sellers, James G. Dagron, George L. Vose, J. B. Davis, and E. Thacher. The paper was also discussed by Mr. C. C. Schneider. It is intended to publish this paper, with the discussions, in an early number of the "Transactions." An abstract of the paper and the extended discussions can hardly be given with justice to the writers.

Engineers' Club of Philadelphia—Record of Eighth Annual Meeting, Jan. 9th, 1886.—The retiring President, Mr. Joseph J. de Kinder, read the annual address. The usual review of the engineering of the past year is given. Special mention is made, with much interesting description in detail, of the following proposed or progressing works: the Panama, Manchester, enlargement of Suez, Corinth, Baltic and North Sea, new Chesapeake and Delaware, Hennepin, Paris and Dunkirk, and Gulf of Siam and Indian Ocean Canals; the reclamation of land in Russia and Missouri and Arkansas; the Baltimore & Ohio at Havre de Grace, Tay, Forth, St. Lawrence, Ohio at Henderson, Ky., and St. John Steel Cantilever Bridges; the Croton and Washington Aqueducts; the Mersey, British Channel, Prince Edward's Island, and Chicago River Tunnels; the Tehuantepec Ship Railway; Railroads in China, Japan, Russia and America; the London and South-western Railway Station; Shipbuilding and Gunnery; the Flood Rock Excavation; Natural, Hydrogen, and Sawdust Gases; the progress in Electric Lighting and Power; and concluding with Water Supply, Sewerage and general Municipal Engineering.

He specially recommends that the latter be made a special question of study and discussion by the Club, and asks if it would not be profitable to ourselves and to the interest of the city if the Club would make the engineering of Philadelphia and its public improvements a leading topic in the future.

The tellers of election, Messrs. E. S. Hutchinson and C. Frederick Moore, reported that the following had been elected officers for 1886:

President—Mr. Washington Jones.

Vice-President—Mr. Thomas M. Cleemann.

Secretary and Treasurer—Mr. Howard Murphy.

Directors—Messrs. Frederic Graff, Rudolph Hering, William A. Ingham, Col. William Ludlow, and Henry G. Morris.

Active members—Messrs. Albanus L. Smith, Samuel T. Williams, Robert E. Pettit, and H. R Cornelius.

Mr. Washington Jones took the chair for 1886 with appropriate remarks.

Engineers' Club of St. Louis.—Prof. J. B. Johnson presented a paper to be read, by title, "The Adjustment of a Quadrilateral."

The secretary read a letter from Mr. Wm. T. Blunt, Sec. Ex. Board of Temporary Civil Engineers' Committee on National Public Works, also one from L. E. Cooley, President of that Board.

Moved and seconded that a standing committee, consisting of five members of this club, be elected to consider and report upon such question as relate to the conduct of our National Public Work, and to act in conjunction with similar committees of other societies. Carried.

Moved and seconded that nominations be made and votes be taken for five, and the five receiving the highest number be declared elected. Carried.

Moved and seconded that the committee elect their own officers. Carried.

The following gentlemen were nominated, and the ballot resulted in the election of Messrs.

McMath, R. Moore, J. B. Johnson, Holman and Ockerson.

Resolved—That the standing committee just elected be entitled the Standing Committee on National Public Works, and that its chairman be a full member of the Civil Engineers' Committee on National Public Works, as suggested by the Cleveland Convention, but no action of this committee shall be held as binding this club until it shall have been reported to and endorsed by the club. Carried.

Moved and seconded that the conclusions of the Cleveland Convention be referred to the standing committee to report at next meeting of the club. Carried.

ENGINEERING NOTES.

GERMANY has decided upon constructing a North Sea and Baltic ship canal, and the Reichstag will soon be asked to vote the money for it. In referring to the project, the Berlin *Post* says: "Prince Bismarck is not the first statesman who devised a waterway between the German Ocean and the Baltic available for war and trading vessels of the largest size. At the time when Wallenstein's 'Grand German' schemes seemed to be near their execution, this statesman, who, among his other dignities, was appointed Imperial Admiral, cast about to establish a German sea power on the Baltic, and conceived the idea of uniting both German coasts by a canal running through Schleswig-Holstein. But, with the other high-flying plans of Wallenstein, this idea came to nothing, though it was shortly afterwards taken up by Cromwell, who, when Protector, in close alliance with Sweden, aimed at securing to England by this enterprise the hegemony of the Protestant nations of Northern Europe His plan, indeed, went so far that the line of the projected waterway was actually fixed. Leaving the Elbe, the canal was to follow the Eider, and, passing through the Lake of Schwerin, enter the Baltic near Wismar, which would thus be converted into a kind of Northern Gibraltar. But technical difficulties delayed the commencement of the enterprise, and death snatched away the mighty man before he succeeded in removing the difficulties that stood in his way."

MR. BENJAMIN BAKER, in his address to the Mechanical Science Section of the British Association, said: "Members of this Section who visited the United States last year not for the first time could hardly have failed to notice that American and European engineering practice are gradually presenting fewer points of difference. Early American iron railway bridges were little more than the ordinary type of timber bridge done into iron, and the characteristic features, therefore, were great depth of truss, forged links, pins, screw-bolts, round or rectangular struts, cast-iron junction pieces, and, in brief, an assemblage of a number of independent members, more or less securely bolted together, and not as in European bridges, a solidly riveted mass of plates and angle-bars. At the present moment the typical American bridge is distinctly derived from the grafting of German practice, on the original parent stock. Pin connections are still generally used in bridges of any size, but the top members and connections are more European than American in construction, whilst for girders of moderate span, such as those on the many miles of elevated railway in New York, riveted girders of purely European type are admittedly the cheapest and most durable. From my conversations with leading American bridge builders, I am satisfied that their future practice and our own will approach still more nearly. We should never think of building another Victoria tubular bridge across the St. Lawrence, or repeat the design of the fallen Tay Bridge, nor would they again imitate in iron an old timber bridge, or repeat the design of the fallen Ashtabula bridge. In one respect the practice in America tends to the production of better and cheaper bridges than does our own practice, and it is this: each of the great bridge-building firms adopts by preference a particular type design, and the works are laid out to produce bridges of this kind. It is an old adage that practice makes perfect, and by adhering to one type, and not vaguely wandering over the whole field of design, details are perfected and a really good bridge is the result. Engineers in America, therefore, need only specify the span of their bridge, and the rolling load to be provided for, with certain limiting stresses, and they can make sure of obtaining a number of tenders from different makers of bridges, varying somewhat in design, but complying with all the requirements With us, on the other hand, it is too often the privilege of a pupil to try his 'prentice hand on the design for a bridge, and it is no wonder, therefore, that many curious bits of detail meet the eye of an observant foreigner inspecting our railways.

The magnificent steel-wire rope suspension bridge of 1,600 feet span, built by Roebling across the East River, at New York, well marks the advanced state of mechanical science in America as regards bridge-building It is worthy of note that, at the second meeting of the British Association, held so long back as 1832, there was a paper on suspension bridges, and the author entreated the attention of the scientific world, and particularly of civil engineers, to the serious consideration of the question, "How far ought iron to be hereafter used for suspension bridges, since a steel bridge of equal strength and superior durability could be built at much less cost?" "I earnestly call upon the ironmasters of the United Kingdom," said he, "to lose no time in endeavoring to solve this question." In this, as in many other engineering matters, America has given us a lead America is, indeed, the paradise of mechanics. When the British Association was inaugurated, years ago, there was, I believe, no intention to have a section for the discussion of mechanical science. Possibly it may have been considered too mean a branch. Even the usually generous Shakspeare speaks contemptuously of "mechanic slaves, with greasy aprons, rules, and hammers"; and our old friend, Dr. Johnson's definition of "mechani-

cal" is "mean, servile." We have lived down this feeling of contempt, and the world admits that the "greasy apron" is as honorable a badge as the priest's cassock or the warrior's coat of mail, and has played as important a part in the great work of civilizing humanity and turning bloodthirsty savages into law-abiding citizens.

As I have had occasion to refer to Canada and America in the course of my remarks, I cannot refrain from expressing the high appreciation which I am sure every member of this section entertains of the cordiality and warmth of our reception on the other side of the Atlantic last year. Such incidents make us forget that differences have ever existed between the two countries.

IRON AND STEEL NOTES.

STEEL.—The *Engineer*, in reviewing the progress of steel manufacture in 1885, says: Probably the most important subject connected with mechanical engineering to which we can refer is steel. No advance whatever has been made during the last ten years towards the elimination of the treacherous characteristics of the metal, and there is no reason to anticipate that it will be better 1886 than it was in 1885. Indeed, there is some cause to fear steel is not so good as it was. Steel made by the Bessemer process at all events does not seem to enjoy the reputation it once did. It would be interesting to know why Siemens steel has come to be regarded by boiler makers and engineers as better, in the sense that it is more trustworthy than Bessemer steel; and it may yet be that the product of the converter will be mainly devoted to rails and tires and axles, while boiler plates will be produced only by the Siemens process. So far as can be known, the unexpected fracture of steel plates is due to the spreading of extremely fine initial cracks in a way very clearly set forth in our last impression, and this can only, we fear, be controlled effectually by giving the plate a fibrous structure. Iron has been much abused for its laminated fracture, but it is the lamination of iron that has enabled it to attain the high position which it long held. The effect of lamination may be made clear by supposing that a boiler, instead of being built up of single plates 1 in. thick, was composed of four plates each ¼ in. thick, put together much as the coils of a gun are In the first case, if a crack was once developed in, say, the outside of the single plate, it would quickly spread inwards, and cause the destruction of the boiler; but the outer plate of a shell built up of four plates being cracked through, the strength of the boiler would only be decreased 25 per cent., and the crack could not spread through the remaining plates. It is for this reason that we look on the metal produced by the Congreaves Company with considerable favor. It is made by putting a number of wrought-iron rods into an ingot mould and pouring steel in. The rods become welded to the steel without losing their fibrous nature. When the ingot is rolled down this wrought iron partakes of the general reduction of section, and thus a plate or rod of very perfect mechanical texture is produced. It ought to be possible, however, to carry this system further, and to produce boiler plates in which iron shall be, so to speak, sandwiched, for the express purpose of stopping the spread of cracks. How these cracks are generated is a very important question. They may be due to the cellular structure of the ingot, the cells being, of course, due to occluded gases. Some of the cells may be quite too small for easy detection, even if an ingot were broken across, and yet develope into a dangerous crack. A very interesting paper, entitled "Théorie Cellulaire des Propriétés de l'Acier," by MM. Osmond and Werth, has just been published in Paris by M. Dunod, Quai des Augustins This does not refer to the gas cells of which we have just been speaking, but to what we may term the microscopical structure of steel. We have not space to quote from this pamphlet at length, but we may state briefly that the theory of the authors, based on microscopical and other researches, is that when heated steel loses its carbon, owing to dissociation, as it cools slowly it recombines with a portion of this carbon, but not all; that some carbon is left free until the steel is tempered, when that carbon before free is re-combined; and that a steel bar really consists of an agglomeration of grains of steel secured to each other by a cement. Speaking of the cooling of an ingot and tracing the structural changes down, the authors say, "Finally, there remains in the fluid state a mixture, more or less complex, commonly dominated by carburet of iron, which solidifies in its turn in the joints of the 'globulites,' and unites them into a solid block—c'est le ciment." The steel may be regarded as in the condition of a number of kernels surrounded each by an envelope of cement, and the strength of the steel depends on that of the cement. It is impossible to do justice in a limited space to the working out and proof of this theory. According to it, the cement not being equally distributed through the material, there may be, so to speak, small centers of weakness in it. We quote the author without translation: "Mais, comme le ciment n'est jamais réparti d'une façon absolument uniforme, certain noyaux peuvent briser leur enveloppe plus mince sous une pression plus faibles, d'autres, qui n'ont pas de'enveloppe sur une ou plusieurs faces, se déforment plus facilement encores; de la ces déchirures parfois visibles à la surface des barreaux d'épreuve, et les bruits que l'on entend pendant l'essai; *chaque cellu'e a en réalité sa limit élastique*, et celle que l'on attribue à l'acier ne correspond qu'un maximum d'un phénomène plus ou moins irrégulier." The author further states that shocks and vibrations, by breaking up the cement by degrees, will gradually reduce a bar of steel to a sort of metallic sand. It will be seen at a glance how important a bearing this theory has, if true, on that which attributes the treacherous fracture of steel to minute initial cracks, as set forth by "L." in our last impression. If the elastic limit varies throughout a bar or plate, then if this limit be once exceeded anywhere over ever so small an area, we may at once have a crack localized for the time

being. Nothing but stress is required to develope it. This theory, too, very satisfactorily explains what has been pointed out by Mr. Parker and others, namely, that the more work we put into a plate, that is to say, the oftener it goes through the rolls, the more likely is it to be honest.

Reference has been made in our columns to the failure of certain ship plates and angles in the North. It is not quite as easy as is desirable to get at the whole truth in these cases. Our inquiries have resulted in the acquisition of information to the effect that such failures have been comparatively numerous, and that the treacherous plates and angles have been in all these recent cases made of basic steel. It will be seen, however, from the letter of our north-eastern correspondent, that such failures are not confined to basic steel. Messrs. Bolckow, Vaughan & Co. have in consequence stated that they will make no more basic plates or angles; and Lloyd's Committee have resolved not to class any ship built of basic steel, and have withdrawn their inspectors from yards where basic steel is used. This line of action must, however, be regarded as only provisional. As soon as the character of basic steel is re-established, it will be accepted by Lloyd's as a material suitable for the construction of ships. For certain purposes it appears to be an excellent metal, but it requires special treatment. Lloyd's will permit boilers to be made of it, but only certain stipulations. Its strength must not exceed about 24 tons on the square inch, and the scantlings must be augmented as compared with acid and Siemens steel standing 30 tons. In fact, it appears to resemble Low Moor or Bowling iron more than anything else. It is worth notice that Lloyd's will not pass any steel which stands more than 30 tons, and when plates exceed 1 in. in thickness the standard is lowered. In all this, we find direct evidence that practical men find it necessary to employ steel with much caution, notwithstanding the admirable qualities which it displays. We understand that Mr. Parker, chief engineer surveyor at Lloyd's, is now conducting a valuable series of experiments with a view to solve the steel problem, and ascertain why plates break. To this end he has subjected steel plates of all kinds to the worst possible treatment—such as heating one corner while the rest is kept cool, making a hot fire on the center of a plate while a hose played on the metal outside the heated circle, and so on—but up to the present he has not succeeded in a single instance in getting a plate to crack.

It cannot be said that any failure of a steel plate is a surprise, because the treacherous character of the material under certain conditions of treatment has long been known. A valuable report to Lloyd's Committee on the steel manufacturing and engineering works of France was prepared by Mr. Parker in 1883. This report is not as well known as it should be. Among other places visited was the Naval Dockyard at Toulon. There they had been long aware of the peculiarities of steel. "The French engineers," says Mr. Parker, "seem to have recognzed to a greater extent than has been done in England the fact that steel requires to be heated with much more care than iron, in order to preserve the normal qualities of the material in a structure; and the plate and angle shops in Toulon Dockyard are fitted with special tools, mostly hydraulic, so that it may not be necessary to hammer or distress the material in any way. These tools are so designed, and the plant is so arranged, that all the work necessary in either plates or angles may be done while the material is at a uniform heat, and before the temperature falls below the acknowledged dangerous limit of dark red. The frames are all heated in gas furnaces on the Gorman system, and by means of ropes, hydraulic capstans, and return pulleys, the frames are turned or drawn to their required curvature in a few seconds of time without any sudden shock or jar; they are then beveled with squeezers, and when completed retain a sufficient heat to anneal them. Again, all garboard strake plates and others involving strong curvatures or sharp changes of form, that in this country are generally bent or flanged by hammers, are at these works bent to form by hydraulic presses, while all shears and punches are also worked by hydraulic power, so that there is a complete absence of jar or jerk in the speed of the tool at the moment when its edge comes in contact with the work punched or sheared, which must necessarily punish the material to a less degree than punches, presses, or shears driven by mechanical gearing. Further, with a view to avoid all useless punishment to the material by punching out curves, circular and curved hydraulic shears are extensively used, and I also observed that for cutting frames, beams, etc., circular and hand saws are used as much as possible. In fact, wherever it is possible to replace hand tool labor, the work of which must be rough and costly, machine tool labor has been introduced, which is much more regular and uniform, and injures the material so little that scarcely any annealing is necessary, and a fractured or cracked plate or angle, such as was so common here a few years ago, is almost unknown at these works." Further on Mr. Parker says: "In view of the valuable information and experience gained during my visit to the Toulon yard, where steel has been so largely employed for the last ten years, I cannot but feel it is a matter for regret that, upon the introduction of steel for ship-building and boiler-making into this country some four years ago, recourse should not have been had by the society's officers to the experience of the French Government officials in the matter. If a visit had then been paid to the dockyards in France, it would, I doubt not, have saved both the committee and executive a great amount of anxiety, inseparable from the society's officers having had to work out for themselves the problems connected with the subject which experience alone could satisfactorily solve."

THE MANUFACTURE OF STEEL CASTINGS.—At the opening meeting for the winter session of the Iron and Steel Works Managers' Institute, held at Dudley on September 12, Mr. R. Smith-Casson in the chair, Mr. B. F. McCallem, of Glasgow, read a paper on "Steel Castings," which developed an interesting discus-

sion upon steel-casting practice. Mr. McCallem said that it was thirty years since the first crucible steel castings were made in Sheffield in the general way, and with one exception the method of manufacture was pretty much the same now as at that early date. The improvement was the employment of gas furnaces instead of the old coke holes for melting. Important economies had resulted from this introduction. Where before it required 3 tons of coke to melt 1 ton of steel, the same thing was now done with 35 cwt. of very poor slack. Though it was apparently easy to make crucible steel castings, it was not, in reality, easy to make a true steel—that was to say, to make a metal that contained only the correct proportions of carbon and silicon and manganese. The only real way to make crucible castings of true steel was to melt the proper proportions of cast steel scrap with the proper amounts of silicon and manganese to produce that chemical composition which was known to be necessary in best castings. It was in consequence of this difficulty that many makers resorted to the addition of hematite pigs. The Bessemer process was used much more extensively upon the Continent than in this country in the manufacture of castings. It seemed likely that Mr. Allen's agitator for agitating the steel in the ladle so as to remove the gases, would be taken up largely for open-hearth castings, and open-hearth mild steel, as it had a wonderful effect The Wilson gas-producer, working in conjunction with the open-hearth furnace, had recently produced some extremely wonderful results. In some large works steel was, by its aid, being melted from slack, which was previously absolutely a waste product. The method of making open-hearth steel castings might be varied greatly. The ordinary method generally practiced in this country was a modification of the Terre Noire process. The molds employed were only of secondary importance to the making of the steel itself. Unless the mold was good, no matter how good the steel was, the casting was spoiled. The best composition which had been found for molds was that of a large firm in Sheffield, but unfortunately it was rather expensive. A good steel casting ought to contain about 0.3 per cent. carbon and 0.3 per cent. of silicon, and from 0.6 to 1 per cent of manganese. Such a casting, if free from other impurities, would have a strength of between 30 and 40 tons, and on an 8-inch specimen would give an elongation of 20 per cent., or even more It was possible by the Terre Noire process to produce by casting as good a piece of steel as could be made by any amount of rolling and hammering.

The chairman said that as they had so high an authority as Mr. McCallem present, Staffordshire men would like to know his opinion upon the open-hearth basic system, in which they were greatly interested.

Mr. McCallem said that he believed that the basic process would be worked successfully in this country in the open-hearth furnace before it would be in the converter. At the Brymbo Works, in Wales, he had seen the basic process worked very successfully in the open-hearth furnace; and he was recently informed by the manager that he was producing ingots at the remarkably low sum of 65s. per ton.

The chairman said that some samples which had been sent into Staffordshire from Brymbo for rolling into sheets had behaved admirably. He thought that the Patent Shaft and Axletree Company, at Wednesbury, were at the present moment putting down an open-hearth furnace on the basic process.

The discussion was continued with considerable vigor by Messrs. H. Fisher (vice-president), James Rigby, J. Tibbs, M. Millard, Walker, W. Yeomans (secretary), and others. Several of these gave it as their experience that the best castings contained the most blowholes, and Mr. McCallem accepted the pronouncement with some slight qualification. A vote of thanks to Mr. McCallem concluded the proceedings.

RAILWAY NOTES

THE United States is now sending abroad about three million dollars' worth of locomotives per annum. This, at an average of ten thousand dollars each, represents about 290 engines.

THE method of placing electric lamps in front of locomotive to illuminate the line has been tried on many lines, but apparently has not found much favor. Recent experience in Russia appears to show that financial considerations are not alone unfavorable to the system. On the railway between St. Petersburg and Moscow several locomotives were fitted with electric lamps. For a time they gave great satisfaction, lighting the way more than a kilometer in front. But the servants began to complain of the contrast between the lighted and the unlighted surfaces painfully affecting the eyes; and doctors ere long reported that there had been several cases of grave injury to the eyes in this way. Hence the lamps were abandoned. The directors have not, however, given up the idea of better illumination for the line, and they now contemplate placing electric lamps so as to illuminate about one kilometer on either side of the station.

A CONCESSION has been granted by the Swiss Government to a firm of electrical engineers at Geneva, for making a railway up Mont Salève, near that city. The line will be laid with a central rack, very similar to that of the Righi railway, but the toothed pinion on the locomotive, which gears into it, instead of being driven by steam, will be worked by electricity.

ACCORDING to the *Brésil*, the total length of the railways of the Brazilian Empire is 8,123 kilos. (5,033 English miles), of which 6132 kilos (3,802 miles are opened for traffic, and 1,991 kilos. (1,234 miles) are still in construction. The railways belonging to the Government have a length of 1,457 kilos. (903 miles), and represent a value of about £11,440,000 sterling. Of these the Don Pedro is the most important, measuring upwards of 700 kilos. (434 miles), and representing a capital of about £8,000,000 sterling.

ORDNANCE AND NAVAL.

SUMMARY OF EXPERIMENTS MADE BY THE SWISS ARTILLERY, IN 1884.—Two steel Krupp guns of 12 centimeters bore and hooped, were modified to allow the use of a percussive apparatus for ignition, which had been sucessful with an 8 4 centimeter gun; the results in this case being also satisfactory, it was adopted by the committee. The gas-check was of copper, and the committee proposed that two guns should be made of bronze mandriné, in order that the national industry might be enabled to take part in the armament of the country.

The bore of 12 centimeters, being small for a siege piece, it was desired to increase the effect of its shells. Two shells, made at the Gruson Works, were fired in comparison with ordinary shells and powder charge. The result gave no marked superiority for the Gruson shells, and as their preparation was longer and more complicated, further trials were suspended. Experiments were made to determine the influence of eccentricity in projectiles on the accuracy of their range, and the limits to be allowed in their manufacture. As an eccentricity of 2 millimeters had a sensible effect on the accuracy, the limit was reduced to 1 millimeter.

Experiments with Shrapnel shell, with rear chambers and double-action fuzes for long ranges, resulted in frequent bursts in the bore, due to premature action of the striking apparatus of the fuze. This was overcome by shortening the striker; a disk of hardened lead was placed underneath, and a spiral spring above it; at the same time the rear ring of the Shrapnel was modified.

Advantage was taken of these trials to study the effects of Shrapnel. They were charged with hard lead balls of 2 calibers, weighing 15 and 12.5 grains, 395 to 400 balls of 15 grains, and 475 to 480 of 12 grains. At 3,000 meters the Shrapnel with small balls gave one-fourth more hits than those with large balls. The number of planks touched was also slightly greater with the small balls. At the same range the penetrative force of the small balls seemed to be equal to the larger ones, and the committee adopted balls of 12.5 grains.

The bodies of shells made in Switzerland of steeled wrought-iron were generally deformed on impact, and the heads remained unbroken, whilst those of Krupp, of steel, were uninjured and the heads always broken.

The carriage was furnished with two shoes specially destined for skidding, but provided with chains to allow the skidding during firing if necessary.

A model ammunition-case, containing five projectiles or ten cartridges, each case for projectiles containing six fuzes and ten percussion tubes, was established, and each gun allotted two hundred rounds of ammunition and ten extra cartridges. Powder of 16 to 18-millimeter size of grain was used, but pressure being too high, the charge was reduced to 4 25 kilograms. Various samples were tried, wood-powder, octagon and pentagon. Octagon gave the best results. The size of the grains was varied from 13 to 19 millimeters without any inconvenience. A transportable platform, proposed by Lieutenant-Colonel Greesly, was tried, with results which give reason to hope that such platforms will constitute a notable progress in guns of position.

A 12-centimeter mortar, fitted with percussion ignition, was tried with a Greesly transportable platform, and also a field-carriage. The mortar was made from a 10.5 inch gun, shortened by 0.50 millimeter and bored out to 12 centimeters; both platform and carriage were adopted for service use.

A short 15 centimeter bronze gun, which was useless after heavy firing, was re-tubed with bronze to see if it could be rendered serviceable. The projectiles were rotated by copper bands. At first the tube behaved well, but gradually it projected and separated itself from the gun; a cap was then screwed on the muzzle, but the extension still proceeded, and the re-tubing of bronze guns was abandoned.

A ten-barrel Gatling gun was tried. The barrels were those of Gras rifles. The mechanism worked well up to one thousand two hundred rounds per minute; at known distances the accuracy was good, but at great and unknown distances it was poor. The result of the experiment was the adoption of a six-barrel gun. To avoid premature bursts of shells in the bore, shells were fired with ordinary and a binary powder; also a bursting composition supplied by the Federal Powder Administration. The binary powder was composed of 87 saltpeter and 13 charcoal, and 80 saltpeter and 20 charcoal The bursts were much weaker than with ordinary powder. The initial velocity of a charge of binary powder was much less than the ordinary, but the pressure was also much lower than usual.

IMPROVED RIFLE FOR THE BRITISH ARMY.—The results of the labors of the committee appointed to provide a new and improved rifle for the army, which has just been published, show, says the *Times*, that the future weapon of the British army will, as regards most considerations, be far in advance of the service arm of any other nation. In the new weapon the Martini breech action has been retained, the alterations being in the barrel and the weight of the projectile, the combination being called the Martini-Enfield. Taking the Martini-Henry as a standard of comparison, the diameter of the bore has been reduced from 0.46 inches to 0.40 inches, the weight of the new bullet being 384 grains, as compared with the 480-grain bullet of the old rifle. The powder charge, however, of 85 grains remains the same, with the important result that the muzzle velocity of the bullet is increased from 1,315 feet per second to 1,570, thus lowering the trajectory to such an extent that, while the Martini-Henry bullet in traveling 500 yards rises more than 8½ feet above the line of sight, the improved projectile would scarcely go over the head of an infantry man if fired from the ground level. This is a most important consideration, as it minimizes any errors in elevations which might arise either from excitement or miscalculation. The system of grooving adopted is the ratchet, the number of grooves being nine, as against the seven of the Martini-Henry, although the latter

is the largest number employed in any military rifle in the world, while the twist of the bullet has been increased from one turn in 22 inches to one turn in 15 inches, the latter being again in excess of anything which has yet been used for service purposes. In addition to the important reduction in the height of the trajectory, the higher velocity of the bullet and the improved rifling have shown remarkably good target results, the mean deviation of the new bullet being only 0.3 foot, and 0 95 foot at 500 and 1,000 yards respectively, as against 0.55 foot and 1.85 foot for the Martini-Henry. Another very important feature is that the recoil of the new weapon is considerably less than that of the present service arm, which has caused so much adverse comment. Experiments are also being made to provide the new weapon with an attachable magazine, so that in cases of emergency the soldier will be able to deliver a rapid fire of several shots without reloading.

BOOK NOTICES

PUBLICATIONS RECEIVED.

REPORT of a Commission appointed to Consider a General System of Drainage for the Valleys of the Mystic, Blackstone and the Charles Rivers. Boston: Wright & Potter.

Report of the Surgeon-General of the United States Navy.

Professional Papers of the Signal Service:

No. XVI.—Tornado Studies for 1884. By John P Finley. Washington: Signal Office.

Papers of the Institution of Civil Engineers:

No. 2081.—The Design and Construction of Railway Rolling Stock in Italy By S. Fadda.

No. 2089.—Evperiments on the Measurement of Water over Wiers. By Bryan Donkin, Jun. M. Inst. C. E., and Frank Salter, Assoc. M. Inst. C. E.

A Lecture on Gas and Caloric Engines. By Professor Fleeming Jenkin, LL. D.

MANUAL OF TELEGRAPHY. By W. WILLIAMS, Superintendent Indian Government Telegraphs. 327 pp., 8vo (*illustr.*) London: Longmans, Green & Co; New York: D. Van Nostrand. Price $4.20.

The fact that this manual was written to order by the Director-General of Telegraphs in India, and that its object is the instruction of the staff, intimates that it should be a practical work. A superficial glance at its contents proves that such is the case, and while the character of the service upon which it is based is such that much of the information is not applicable to the American telegraph systems, it contains sufficient matter of a general character to render it a valuable text-book even in this country. The work is divided into six section. Section A embraces electrical and magnetic definitions; section B, telegraph batteries; section C, signaling instruments; section D, telegraphic circuits; section E, faults in circuits, and their remedy; section F, testing. In an appendix are grouped the laws of currents, of circuits, and of induction; also various formulæ and their solutions, with tables of sines and tangents.

The section devoted to batteries is very complete, and gives not only comprehensive instruction as to their care, but the principles which govern their action. The various types of battery with which our readers are familiar are described, the preference in the Indian service, however, being in favor of the Minotti form, which is essentially the same as the ordinary gravity cell, the sulphate of copper being, however, surmounted with a diaphragm of river sand or sawdust. Each of these materials has its advantages, the choice being governed by circumstances. In the climate of India it might at times be easier to gather sand than saw wood, while if the saw-dust was at hand there would be no occasion for a trip to the Ganges. On account of the time required to bring new cells into working condition, a reserve force is usually kept on hand, from which the zincs are removed (to avoid waste from local action) to be replaced as required.

The Fuller battery has been used to some extent, but is considered as less convenient, and, at the same time, more expensive than the Minotti. The great advantages of the latter are summed up as being due to the constancy of its E.M.F., which remains the same from the time the battery comes into action until it is exhausted. It does not depend upon the strength of acid solutions, and the hydrogen generated by the action of the battery, which is the great enemy to constancy when in its free or uncombined state, by virtue of its polarizing effects, is prevented from remaining free by its immediately combining, by chemical affinity, with the sulphate of copper solution, and taking the place of a certain amount of copper which it reduces from the solution, depositing it on the copper plate immersed therein, the plate being thus continually supplied with a fresh, bright copper coating, as long as the action of the battery continues.

Thirty-ohm sounders being generally used, four local cells in series are necessary to the best effect. A standard cell is kept in every office as a unit of E.M.F., being prepared with special care, and used only for testing.

The Siemens polarized relay is universally adopted for departmental use, but it appears not to be wholly satisfactory, excepting for *double-current* working, on account of the small margin for proper adjustment. The efficiency of a relay is tested by its range, obby the following rule:

"Adjust the relay with minimum play, with the tongue as far from the metallic stud as regular working will admit of, so that it will work with one cell through a resistance equal to its own; then apply ten cells without any external resistance; the relay should work without readjustment, thus displaying a range of 20, the minimum range a Siemens relay should exhibit."

The Siemens-Morse sounder is generally used, constructed upon the same principle as the American sounder, but of a less elegant pattern, and with apparently less attention to its sound-producing qualities. Repeating points appear to be considered as essential to a complete sounder. The armatures are of thin, iron plate, bent cylindrically, the edges not

joining. The following rather elaborate directions are given for proper adjustment of the spiral spring:

"Adjust the spiral spring by the following process: Work the sounder electrically, and tighten the spring until the magnet is unable to attract the armature; mark the position of the screw on the stem; now loosen the spring until the armature falls on the electro-magnet by its own weight; mark the second position on the screw, then tighten the screw to about midway between the two marks. N. B.—Fix all jam-nuts securely."

Two other forms of sounders are shown—the Douglas and the Dubirn. The former is similar to those used in this country previous to the advent of the pony sounder. The lever is pivoted in the center like a walking beam, with a sounding post at each end, one for the direct, the other for the back stroke. The Dubirn sounder is designed to utilize the strongest magnetic field. The magnet is placed with its poles downward, and resting on the base, they being extended beyond the helices for a sufficient distance to permit the armature to play between them, it being centered on a pivot midway between the coils. One end of the prolonged armature acts as the sounding part, its excursion being limited by appropriate screws fixed to the base of the instrument.

The portable sounder is a polarized instrument of a pattern which would not find favor with those who are accustomed to the very compact and serviceable outfits produced by American manufacturers, for transportation in the pocket.

Various forms of signaling keys are shown, a description of the discharging key leading up to a very clear explanation of the effects of static induction, upon a well-insulated line, to obviate the effects of which a transmitting device of this character is essential for the purpose of clearing the line between signals. The author says:

"Induction is the main cause which diminishes the speed of signaling; first, by accumulating on the surface of the wire a portion of the current which would otherwise pass on to form signals; the quantity accumulated depending upon the length and surface of the wire, upon its proximity to the earth, and upon the insulating medium which separates it from the earth. For this reason the electro-static capecity of cables is much greater than that of land lines—*i. e.*, they hold a much greater charge. The greater this electro-static capacity, the less the speed, for it causes the first portion of a sent current to be absorbed or accumulated as shown above, and thus it retards the first appearance of the signal at the distant end. Again, at the cessation of the signal the accumulated charge takes an appreciable time to discharge, and consequently each signal is prolonged. Thus, 'charge' *produces retardation, and* 'discharge' *prolongation.*"

The various common forms of galvanometers and their applications are set forth under the head of testing instruments.

Section C, devoted to magneto-electric instruments, embraces the telephone, and, as naturally associated with it, the microphone transmitter.

A very complete table of electrical symbols for use in diagrams, is given in the space allotted to telegraphic circuits. The open circuit system is generally used in India for the departmental wires, while the closed circuit is used on the State railway lines. The principal duplex circuits are worked on the double current differential system. The bridge and split battery duplex systems are fully described, also Gerrit Smith's battery reverser, and all are more or less used in the Indian service.

For office connections, Hooper's india-rubber-covered wire is given preference over gutta-percha, and it is advised that every joint should be soldered, excepting the terminals at binding screws, which should be kept scrupulously clean.

The development and removal of faults is a most important part of successful telegraphic administration, and in this respect the author has performad a most important duty in pointing out the various ills to which the most perfect electrical system is continually subjected. The electrical and mechanical faults encountered are similar to those which worry the wire chief wherever he may be located.

The last section of the manual gives various methods of testing in all its branches. The peculiar character of the Indian service requires that particular attention be gixen to the regular testing of the lines, in order that any departure from the normal condition of the circuits may be at once detected and electrically located. The Wheatstone bridge is universally used for this work.

In the appendix are given the laws of currents, circuits, electro-magnetism, induction and magnetism, which are convenient of access, and, therefore, add to the value of the book as one of practical utility in the field for which it has been especially prepared

The general arrangement of the subject matter, with its side notes, marginal titles, and cross references is very commendable, and no electrician will fail to appreciate the merits of this "Manual of Telegraphy" by merely glancing over its pages.

ELEMENTARY GRAPHIC STATICS, AND THE CONSTRUCTION OF TRUSSED ROOFS; A MANUAL OF THEORY AND PRACTICE. By N. CLIFFORD RICKER. New York: William T. Comstock Price $2.00.

There is a special feature of this work which will commend itself to students of engineering and architecture. It is exhibited in working out to *completion* the problems of trussed roofs. The general problem of determination of strains in the various members is presented with ordinary fullness. But the author does not rest here; he proceeds to find sectional areas, to arrange details, and to exhibit them in suitable diagrams. This last feature is admirably presented.

Ritter's method is employed, as well as the graphic, in determining strains.

A large number of practical examples is given.

SELECT METHODS IN CHEMICAL ANALYSIS. By WILLIAM CROOKES, F. R. S., F. R. C. S. Second edition. London: Longmans, Green & Co.

To practical chemists the mere announcement of a new and enlarged edition of this valuable work is sufficient. The first edition was exhausted some time ago.

The new methods introduced into laboratory practice since the first edition was written, have rendered a thorough revision necessary. Much of it has been rewritten, and an amount of new matter added nearly equal in volume to the original work.

It is now a book of 725 pages. The processes that are commonly known are purposely omitted, the main object of the author having been to bring into notice a number of little-known expedients and precautions which prevent mistakes, insure accuracy, and economize time.

A Treatise on Belts and Pulleys. By J. Howard Cromwell, Ph. B. New York: John Wiley & Sons.

No mechanical engineer will dispute the desirableness of a reliable treatise on Belting. The discordant results obtained by the different rules given by leading authorities are exceedingly confusing.

The work before us shows evidence of careful preparation, and of complete knowledge of the subject.

The large number of examples will prove to be a valuable aid to the young engineer.

A Practical Treatise on Hydraulic Mining in California. By Aug. J. Bowie. New York: D. Van Nostrand.

An estimate of the scope of this work can be well made from the list of topics treated by chapters. They are, in order, as follows:

Chapter I.—The Records of Gold-Washing. II.—History and Development of Placer-Mining in California. III.—General Topography and Geology of California. IV.—Distribution of Gold in Deposits, and Value of Different Strata. V.—Amount of Workable Gravel Remaining in California. VI.—Different Methods of Mining Gold Placers. VII.—Preliminary Investigations. VIII.—Reservoirs and Dams. IX.—Measurement of Flowing Water. X.—Ditches and Flumes. XI.—Pipes and Nozzles. XII.—Various Mechanical Appliances. XIII.—Blasting Gravel Banks. XIV.—Tunnels and Sluices. XV.—Tailings and Dump. XVI.—Washing, or Hydraulicking. XVII.—Distribution of Gold in Sluices. XVIII.—Loss of Gold and Quicksilver. XIX.—Duty of the Miner's Inch. XX—Statistics of Cost of Working and Yield of Gravel.

The printing and illustrations, including maps, are excellent.

MISCELLANEOUS.

The Russian papers say, that, at the request of General Komaroff, Governor of the Transcaspian region, the Minister of War has recognized the urgency of immediately establishing a line of telegraph connecting Merv with Askabad. This line would pass by Annow, Babadoorma, Bougatchik, Artchigan, and Sarakhs. Its length will be 500 versts, and the expense about 100,000 roubles.

The monthly report of Mr. William Crookes, Dr. William Odling, and Dr. C. Meymott Tidy shows that the character of the water supplied to the metropolis (London) during the past month has been in every respect excellent. The mean ratio of brown to blue tint of color in the Thames-derived water was found to be as 11.4:20; while the mean proportion of organic carbon was .128 part in 100,000 parts of the water, with a maximum in any one sample examined of .148 part; this maximum of organic carbon corresponding to just over a quarter of a grain of organic matter per gallon.

Hellhoffite.—Comparative trials have been made at St. Petersburg respecting the explosive effects of ordinary gunpowder, nitro-glycerine, and a new explosive known as hellhoffite. The latter, which has been recently invented by Hellhoff and Gruson, is a solution of a nitrated organic combination (naphthalene, phenol, benzine, etc.) in fuming nitric acid. In preparing the hellhoffite tried in the experiments, binitrobenzene, a solid, inexplosive, and badly burning substance, was used. At the first trial, glass bottles of 20 cubic centimeters contents each were filled with 25 grammes of the respective explosive substances and corked down. A tube filled with fulminate of mercury was passed through the corks, a slow-match being attached to the outer end of the tube for the purpose of ignition. Each of the bottles thus prepared was placed on a truncated cone of lead, the upper diameter of which was 3.5, its lower 4.5, and its height 6 centimeters. The cone itself stood on a cast-iron plate 2.5 centimeters thick. The deformation of the leaden cone by the action of the explosives could consequently be taken as a measure of their respective destructive power. The explosion of the gunpowder, as was anticipated, caused no change. By the explosion of the nitro-glycerine, the cone was compressed about a quarter of its height; its surface had assumed the appearance of a well-worn hammer; the diameter of the surface had been increased to 5.5 centimeters. The explosion of the hellhoffite caused much greater changes. The surface of the cone was completely torn; pieces 5 centimeters long and 2 centimeters thick were torn off, and thrown about for several paces; only half of the cone was still a compact but entirely defaced mass. At the second experiment, bottles (of 25 grammes each) filled with the various explosive substances were let into corresponding cavities bored into the face of fir blocks of similar dimensions. In exploding the gunpowder, the block was torn into four pieces, as if split with a hatchet; the several pieces were thrown about for 18, 12, 11, and 10 paces. In exploding the nitro-glycerine, the block was split into several pieces. The upper portion of the block, as far as the bottle was let into it, was torn off perpendicularly in the direction of the fiber in such a manner that a smooth cut was formed. The explosion of the hellhoffite likewise tore the portion of the block surrounding the bottle perpendicularly in the direction of the fiber, and splintered the remainder of the block into a large number of thin fibers. The following experiments were also made with hellhoffite alone. A slow-match was passed

through the tube in the cork without fulminate of mercury as far as the surface of the hellhoffite in the glass bottle; no explosion followed on igniting the slow-match. A quantity of hellhoffite poured into a bowl could not be exploded by a lighted match. Finally, a few drops of hellhoffite were poured on an anvil, and exposed to heavy blows with a hammer, and no explosion followed. The hellhoffite, consequently, possesses the following advantages: (1) In igniting it with fulminate of mercury, it acts more powerfully than nitro-glycerine. (2) It may be stored and transported with perfect safety as regards concussion, as it cannot be exploded either by a blow or a shock, nor by an open flame. On the other hand, it has the following disadvantages: (1) Hellhoffite is a liquid. (2) The fuming nitric acid contained in hellhoffite is of such a volatile nature that it can be stored only in perfectly closed vessels. (3) Hellhoffite is rendered completely inexplosive by being mixed with water, and can consequently not be employed for works under water. It would, therefore, be injuriously affected by exposure to damp, and, moreover, there are no records of its behavior under extremes of temperature. Without some experiments in this direction, in our opinion, all the rest is comparatively valueless.

Effect of Encasing Wood with Iron.—It was always expected, since first wooden ships were clothed with armor plates, that they would speedily decay, and this anticipation has been abundantly realized. The only excuse for the armor-plating of the *Lord Clyde*, *Lord Warden*, *Ocean*, *Prince Consort*, *Caledonia*, *Zealous*, *Royal Oak*, *Repulse*, *Royal Sovereign*, *Favorite* and *Research*, was the fact that the vessels were already built or building, and were of no use at all unless so protected. When once those ships of the line were completed that happened to be on the stocks when ironclads were proved to be an absolute necessity, no other wooden ironclads were laid down in this country, but iron ships took their place. But in France wooden ironclads continued to be built until within the last eight years, and it is this fact which has doubtless induced the French Admiralty to lay down so many iron and steel ironclads since that time. It is the closely-fitted wooden backing on the outside and flanking on the inside which entirely prevents air from getting at the unseasoned oak timber of the frames, and this causes the juices of the timber to ferment, and so induces the growth of the peculiar fungus known as dry-rot, An examination of our wooden ironclad fleet a few years ago resulted in their being almost entirely condemned, and now we find the admiralty are turning them into money by selling them to the ship breakers. The *Royal Sovereign*—the ship in which Captain Coles' turrets were first tested—also the *Zealous* and *Favorite*, have just been sold for this purpose, and others will doubtless speedily follow. While vessels of less than twenty-five years old are thus being broken up on account of rottenness, it is interesting to notice the number of two and three-decked wooden ships—some of them nearly a hundred years, and none of them less than thirty or forty years old—which still survive in ordinary use at Portsmouth, Devonport, and Sheerness. These were built of seasoned timber before the age of hurry set in.

A Mechanical Air Purifier.—An apparatus for purifying air from dust, germs, or other impurities, has recently been designed by M. Windhausen. It consists of two horizontal concentric cylinders placed in connection with a fan. The fan and cylinders are fixed upon and turn with the same shaft, and the whole is enclosed in a casing. The cylinders are closed at the ends with the exception of a hole permitting the passage of the air drawn in by the fan. As the air passes through the concentric space between the drums, it is caused to rotate with them by means of feathers running longitudinally on the inside of the outer cylinder. The shaft which carries the whole arrangement is hollow, and serves to convey water which is allowed to escape therefrom inside the drums by means of small holes, which project it in the form of fine spray against the inside of the inner cylinder. This cylinder is also perforated, and the water again escapes from it and is projected against the inside of the outer cylinder, over which it spreads as a thin coating. The motions of the air and water are as nearly as possible in opposite directions. The water, after it has been sufficiently exposed to the air, is allowed to escape, and is drawn off by means of a siphon. The same arrangement may be modified for treating smoke or gases.

Telegraphs in China.—We learn from *Nature* that telegraphs are extending with extraordinary rapidity over Southern China. At the present moment, Pekin, in the far north, is connected by a direct line through Canton with Lungchow, on the frontier of Tonquin, the extension from Canton to the latter place having been made during the recent war purely for military purposes. We have thus one great line stretching through the Chinese Empire from north to south, and at the present moment an important line is being constructed along the southern borders of China, through the provinces of Kwantung, Kwangsi, and Yunnan. Starting from Nanking, in Kwansi, where it joins the Canton-Lungchow line, it will extend for nearly 600 miles to Nung-lik, in South Yunnan, running for half the distance along the Yukiang, the name of the Canton River in its upper course. The work is being carried out by the Chinese themselves, with the assistance of one European, and it is stated that during the recent war the Canton authorities equipped a complete field telegraph staff, the members of which were so thoroughly trained that they have been able to put up 35 miles of line in a single day for war purposes. Telegraphs have now secured a firm footing in China, and their extension over the whole country is a matter of time only.

The *Organe des Mines* seriously states that a company is about to establish large works for making rails from paper near St. Petersburg. The paper is subjected to great pressure, and it is said that the material is extremely durable and can be produced at one-third the cost of steel rails.